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Gel And Saline Drilling Wastes In Alberta
Workshop Proceedings

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

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Report No. RRTAC 87-3

GEL AND SALINE DRILLING WASTES IN ALBERTA

Workshop Proceedings

23-24 April 1985
Edmonton, Alberta

Compiled by

DAVID A. LLOYD

Seminar organized by the
Reclamation Research Technical Advisory Committee
of the
Alberta Land Conservation and Reclamation Council

1987

STATEMENT OF OBJECTIVE

The recommendations and conclusions in this report are those of the authors and not those of the Alberta Government or its representatives.

This report is intended to provide Government and Industry staff with up-to-date technical information to assist in the development of guidelines and operating procedures. The report is also available to the Public so that interested individuals similarly have access to the best available information on land reclamation topics.

Note: The papers in these proceedings have been edited for spelling and format only. The grammar and technical content have been left as submitted by the author.

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ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from the Department of the Environment and two Deputy Chairmen from the Department of Forestry, Lands & Wildlife. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program, the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy, Forestry, Lands & Wildlife, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for reclamation research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

** 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. 2 vols. L.E. Watson, R.W. Parker, and P.F. Polster. 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their fitness for use in Reclamation. Range maps, growth habitat, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of the original report conducted in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stien, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. 2 vols. H.P. Sims and C.B. Powter. 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system. Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981 are available from the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of recently initiated field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop reproduction.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Technical Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing site preparation, planting and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of International Literature. 2 vols. H.P. Sims, C.B. Powter, and J.A. Campbell. 659 pp.

DESCRIPTION: Nearly all topics of interest to reclamation including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. 2 vols. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 676 pp.

DESCRIPTION: This is a collection of five reports dealing with reestablishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design and sizing and alternative technologies. An executive summary outlines the findings.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establishe a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Program. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden at the Battle River Mining area in east-central Alberta to support post-mining land use. Both groundwater quantity and quality are evaluated.

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to suuport post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North Americal literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe, hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed.

27. RRTAC #87-1: In prep.

28. RRTAC #87-2: In prep.

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Edmonton, Alberta T5G 2Y5

* A $5.00 fee is charged for handling and postage.
** A $10.00 fee is charged for handling and postage.
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N/A Not available for purchase but available for your perusal at the Alberta Environment Library, 14th Floor, 9820 - 106 Street, Edmonton, Alberta.

Gel and Saline Drilling Wastes in Alberta

Organized by the
Reclamation Research Technical
Advisory Committee

Date: April 23-24, 1985
Place: Edmonton, Alberta

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INTRODUCTION/BACKGROUND

Waste disposal from oil and gas drilling on the public and private lands in Alberta is a very complex exercise requiring at least a basic understanding of several major resource disciplines. The oil and gas industry is constantly developing new drilling mud technologies to improve petroleum exploration and recovery. These new technologies complicate waste treatment and disposal.

The Reclamation Research Technical Advisory Committee (RRTAC), an interdepartmental body that co-ordinates and reviews reclamation research in Alberta, recognized in 1984 that the oil and gas industry and regulatory agencies were encountering field operational problems when disposing of drilling waste. In response, RRTAC sponsored a two-day seminar on "**Gel and Saline Drilling Waste Disposal**" to promote a better understanding between government regulators and industry about:

a) the mud components used, their purpose and need;
b) constraints on industry with drilling and industry clean-up practices;
c) the environmental considerations when disposing of wastes such as soil, vegetation, ground and surface waters, flora and fauna;
d) government regulations, procedures and concerns; and
e) toxic constituents of drilling wastes.

Seminar participation was solicited from petroleum companies. Soil, water and vegetation researchers, drilling mud and industry specialists, drilling waste treatment companies and government regulators were also seminar contributors. The accompanying proceedings detail the talks given at the seminar. Each paper represents the opinion of the author, and does not represent government or industry policy, opinion or direction.

More than 200 people attended the seminar. A proper discussion time was not built into the seminar to allow good audience/speaker interaction. Seven questions were, therefore, sent out to each person attending and the seminar participants to obtain feedback on the seminar topics. Because of the number of responses received and because the responses were so varied, the answers for each question have been summarized and presented in Appendix A at the back of the document.

Thank you to all who participated in the seminar, either by presenting a paper or by interacting during the sessions.

A special thank you goes to Donna Knutson for retyping the whole document text.

WASTE DRILLING FLUID DISPOSAL

- ERCB DIRECTIVES

G. Berndtsson[1]

I am going to review two of the ERCB's directives on Drilling Fluid Disposal, ID 81-1 and IG-OG 75-2, copies of which have been distributed, if you do not already have them.

WASTE DRILLING FLUID DISPOSAL

Introduction

Since the early days of the oil industry, the ERCB has had regulation requiring proper containment of "liquid waste" from wells, battery or other production facilities. Drilling fluids have been included in that definition of liquid waste. Present Board regulations state that operators must obtain approval from an appropriate Government representative for any off-lease disposal of waste drilling fluids; Alberta Energy and Natural Resources (AENR) on public lands and the ERCB on private lands. These regulations state the licensee of a well or operator of a battery shall ensure that liquid waste is contained at all times, and disposal of such wastes will be a manner that no air, soil, surface water or underground source of potable water is or could be polluted.

By 1973 both the oil and gas industry and government departments were actively investigating the toxicity of drilling mud additives, standard method of test for toxicity, and on-site treatment of drilling fluids.

---

[1] Energy Resources Conservation Board, Calgary, Alberta.

Some of these investigations were tests conducted by the ERCB's Chemical Laboratory which showed that a considerable number of drilling mud additives were fatally toxic to rainbow trout in extremely low concentrations. The test also showed that some substances minimumly toxic by themselves became highly toxic when in combination with other relatively non-toxic materials.

With the trend toward deeper wells and hence greater drillng fluid volumes, and more complex drilling muds it became evident that standards were necessary. Early documents were drafted and discussed by Alberta Environment, AENR, ERCB and Industry through CPA AND IPAC (Canadian Petroleum Association and Independent Petroleum Association of Canada). The outcome of these discussions was the ERCB's Interim Directive ID-OG 75-2 issued August 1975. This was a joint directive by the parties I just mentioned.

In March of 1981 the ERCB issued an additional Interim Directive 81-1 regarding the Subsurface Disposal of Drilling Fluids. This replaced an older ID that had been issued in December 1970 on the same subject.

A Subsurface Disposal of Fluids - ID 81-1

Properly conducted and controlled subsurface disposal is environmentally desirable and is encouraged by the ERCB. The ERCB will permit industry to dispose of drilling fluids not only in unsuccessful holes but to any wells where subsurface disposal of drilling fluids is feasible.

The ERCB will consider such disposal as part of the drilling or completion program for a well. Separate approval under Section 26 of OGCA is not required, a section that deals with approval of disposal of any fluids to an underground formation.

Subsurface disposal can be carried out subject to the following conditions:

- Permission of an ERCB representative must be obtained before any disposal operation is commenced whether it is located on private or public lands.
- The disposal zone shall be at a depth not less than 600 m (protects potable water sources).

- Formation water of the disposal zone shall not havve a total dissolved solids content of less than 20 000 ppm (protect any potential potable water).
- The disposal zone shall be known not to contain hydrocarbons within two kilometres of the intended disposal well.

Where a well is to be abandoned or plugged back, and does not contain at least 600 m of casing cemented in place:

- then the disposal of fluids shall be through drill pipe and below a seated packer, and
- the annulus between the drill pipe and the surface casing shall remain open to the atmosphere during the disposal operation.

Where a second casing string has been run in a well and not cemented to surface:

- the disposal of fluids shall be through the annulus between the casings, provided the surface casing is set deeper than 600 m,
- the disposal zone shall be identified by depth and geological designation,
- the fluids to be disposed shall be displaced out of the annulus with a corrosion inhibited fluid. If, after displacement, pressure exists in the annulus, cement shall be displaced into the formation to seal off the disposal interval, and
- the annulus shall be left open to the atmosphere.

Where the disposal zone has been cemented behind casing:

- the disposal zone shall be identified by depth and geological designation,
- the casing shall be perforated and the fluids disposed of through the perforations, and
- the perforations shall be appropriately sealed or isolated.

Turning now to Surface Disposal of Drilling Fluids as outlined in ID-OG 72-2

Drilling and sump fluids may be disposed on lease provided the following conditions are met:

- The entire contents of the sump are confined to the lease.
- The sump contains less than 6 000 barrels of fluid. More than 6 000 barrels may be disposed on the lease provided the entire contents are confined to lease and the fluids are treated and detoxified.
- The lease is more than 300 feet (100 m) from the normal high water mark of a body of water, permanent stream or potable water well.
- Notice of one week must be given to the ERCB Area Office for wells on private land and to AENR district office for wells on public land.

Drilling and sump fluids may be disposed to off-lease land areas provided the following criteria is met:

1. Sample the fluids, analyse and field treat fluids so that they meet the following

Chloride Content	1 000 mg/L Maximum
Sulfate Content	2 000 mg/L Maximum
Total Dissolved Solids	4 000 mg/L Maximum
pH	5.5 to 8.5
Trout Survival Test	96 hours

2. A request to dispose off lease must also be approved by ERCB Area Office or AENR district office and should contain the following information:
    a) a description of the sampling procedure
    b) a general description of the method of treatment of the sump fluids
    c) an analysis of a representative sample of the treated sump fluids (including trout survival test)
    d) the location of the disposal area and the volume of sump fluids to be disposed of

e) a brief description of the disposal area surrounding area (i.e. whether it is forested, muskeg, swamp and the kind of vegetation present)

f) in the case of disposal to private lands, a statement that the landowner's permission has been obtained to dispose to the off-lease site

Disposal of well sump fluids to any surface water either directly or indirectly by land surface drainage must be approved by Alberta Environment. Only under rare circumstances, and where sufficient lease land or peripheral land disposal sites are not available, is such disposal even considered.

The sampling procedures and the trout test are discussed in Appendices to the directive.

Oil Field Wastes

In the introduction I mentioned "liquid waste" from wells and production facilities. For oil field wastes other than drilling fluids, the Board upgraded its regulations in 1983 to ensure better handling and disposal of oil and gas field wastes. These included provisions for approval of Waste Processing and Disposal Facilities in the Province. These do not cover hazardous materials (outlined in IL 83-10).

At this point I was to discuss present reviews and future changes.

- Obviously the Board and many others have reviewed a number of matters - the reason we are here today as we seem to have come up with more questions than answers
  - on the changing scene on drilling fluid components and additives
  - on various toxicity tests
  - are shallow well sumps just as toxic as deep well sumps (some tests by the Board in 1983 and 1984 seem to say so)
  - the 6 000 bbl limit, while limiting the volume of fluids, produced some sumps with very high salt concentrations that are of concern

What Considerations Can I See Forthcoming

- Should the guidelines used for large sumps (greater than 6 000 bbl) be extended to all sumps regardless of size and depth of well?
- Permit the use of either microtox test or the trout test?

I can make one observation, motherhood as it may seem, we (both industry and regulatory agencies) must plan for adequate and satisfactory disposal of sump fluids as part of the drilling plans for our wells and not wait for the other fellow to do it after the well is finished.

THE PROVINCE OF ALBERTA

ENERGY RESOURCES CONSERVATION BOARD

Interim Directive
No. ID-OG 75-2

TO: All Operators

Sump Fluid Disposal Requirements

Alberta Environment, Alberta Energy and Natural Resources and the Energy Resources Conservation Board have decided that sump fluid disposal standards are necessary. The decision to implement Province-wide sump fluid disposal standards arose due to concern over some of the deeper wells being drilled in the Foothills region of Alberta which result in large quantities of fluids which must be disposed of in an environmentally satisfactory manner.

The requirements outlined in this directive will be reviewed in 12 months time and may be set out in regulation form following a further period of assessment.

In accordance with the provisions of the Oil and Gas Conservation Act and the Oil and Gas Conservation Regulations, these sump fluid disposal requirements have been approved by both the Minister of the Environment and the Acting Minister of Alberta Lands and Forests.

Effective September 1, 1975, the Board requires that all operators comply with the requirements outlined in the attachment to this directive and entitled "Attachment I to Interim Directive No. ID-OG 75-2, Sump Fluid Disposal Requirements".

ISSUED AT Calgary, Alberta on July 23, 1975.

ENERGY RESOURCES CONSERVATION BOARD

D. R. Craig
Vice Chairman

ATTACHMENT I

TO INTERIM DIRECTIVE NO. ID-OG 75-2

SUMP FLUID DISPOSAL REQUIREMENTS

1.0 **Disposal of Sump Fluids to a Subsurface Formation**

Disposal of sump fluids to a subsurface formation is an acceptable procedure provided:

a. Approval is first obtained from the Energy Resources Conservation Board.

b. The subsurface formation is not locally productive of oil or gas.

c. The formation water in the disposal zone has a total dissolved solids content greater than 20 000 mg/L.

2.0 **Disposal of Sump Fluids on the Lease**

Disposal of sump fluids to the lease is an acceptable procedure providing all of the following conditions are met:

a. Notice of at least one week has been given to:

   i. the appropriate District Office of Alberta Energy and Natural Resources if the well was drilled on any public land in the Province.

   ii. the appropriate Area Office of the Energy Resources Conservation Board if the well was drilled on any other lands not specified in section 2.0(a).

b. The entire contents of the sump are confined to the lease.

c. The sump(s) contain less than a total of 6 000 barrels of fluid. Not withstanding this limitation, approval may be given by the Board or Alberta Energy and Natural Resources to dispose of more than 6 000 barrels of fluid to the lease providing it can be shown that the entire contents of the sump will be confined to the site. Applications for such approval shall be directed, in the appropriate case, to either the Area Office of the Energy Resources Conservation Board or District Office of Alberta Energy and Natural Resources.

d. The lease is more than 300 feet from the normal high water mark of a body of water, permanent stream or potable water well.

e. The lease site will, in the opinion of the Energy Resources Conservation Board or Alberta Energy and Natural Resources, accept the sump contents, to be disposed, without run-off.

3. Disposal of Sump Fluids Off the Lease

3.1 Disposal of sump fluids to off-lease land areas is an acceptable procedure providing:

a. The sump fluids meet the following criteria:

Chloride Content	1 000 mg/L Maximum
Sulfate Content	2 000 mg/L Maximum
Total Dissolved Solids	4 000 mg/L Maximum
pH	5.5 to 8.5
Trout Survival Test	96 Hrs. (see Appendix "B" - Guidelines Used to Determine Fish Toxicity Tests on Sump Fluids)

b. Approval to dispose off the lease has been obtained in accordance with section 3.3.

3.2 The Energy Resources Conservation Board or Alberta Energy and Natural Resources will consider off-lease disposal which is not according to the criteria outlined in section 3.1. Application shall be made in the appropriate case, to the Area Office of the Energy Resources Conservation Board or the District Office of Alberta Energy and Natural Resources.

3.3 Off-Lease Disposal Approval

3.31 On public lands throughout the Province, disposal of well sump fluids to land off the lease and the location of the disposal site must be approved by the appropriate District Office of Alberta Energy and Natural Resources.

3.32 On all land not described under subsection 3.31, disposal of well sump fluids to land off the lease must be approved by the Energy Resources Conservation Board, subject to the disposal and disposal site having been approved by the landowner.

3.33 Any licensee of a well who intends to dispose of fluids to land off the lease area shall:

(a) sample the fluids according to the procedure outlined in Appendix A.

(b) analyse and field-treat the sump fluids so that the fluid to be disposed of meets the criteria outlined in section 3.1. Tests must conform to the guidelines outlined in Appendix B.

(c) two days prior to treating the fluids and depending on whether the lease is located on public or other lands, notify, in the appropriate case, the District Office of Alberta Energy and Natural Resources or the Area Office of the Energy Resources Conservation Board.

3.34 The request for approval to dispose of sump fluids to land off the lease area must be submitted, in the appropriate case, to the District Office of Alberta Energy and Natural Resources or the Area Office of the Energy Resources Conservation Board, and contain the following information:

(a) a description of the sampling procedure.

(b) a general description of the method of treatment of the sump fluids.

(c) an analysis of a representative sample of the treated sump fluids (including trout survival test).

(d) the location of the disposal area and the volume of sump fluids to be disposed of.

(e) a brief description of the surrounding area (i.e. whether it is forested, muskeg, swamp and the kind of vegetation present).

(f) in the case of disposal to private lands, a statement that the landowner's permission has been obtained to dispose to the off-lease site.

3.4 Disposal of well sump fluids to any surface water either directly or indirectly by land surface drainage must be approved by Alberta Environment. Only under rare circumstances, and where sufficient lease land or peripheral land disposal sites are not available, is such disposal considered.

APPENDIX A

GUIDELINES FOR OBTAINING A REPRESENTATIVE SAMPLE OF THE SUMP FLUIDS

1. Divide the sump into six segments and then obtain samples near the surface, middle and bottom of each segment. In this way 18 samples will be obtained to form a single composite sample.
2. The minimum composition sample size is two quarts collected in a glass or plastic container.
3. The sample should be submitted for analysis to a reliable commercial laboratory.

APPENDIX B

GUIDELINES USED TO DETERMINE

FISH TOXICITY TESTS ON SUMP FLUIDS

Drilling sump fluids may contain a variety of complex organic and inorganic compounds, the combined effects of which are difficult to ascertain. Therefore, the fish survival test is being used as a part of the criteria to evaluate the toxicity of treated sump fluids.

The person carrying out the test may be reasonably certain that if any fish survives the 96 hour test the treated sump fluids are minimally toxic. However, if both fish die within a very short period of exposure to the treated sump fluids, then further treatment of the fluids is necessary. In cases where it appears that problems are being experienced with fluid detoxification, the Board's Chief Chemist should be consulted.

Requirements of the standard bioassay tests apply as stated in the latest edition of Standard Test Methods[1] except for those points mentioned below:

1. The test fish to be used are small trout fingerlings 4 to 10 cm in length, which have been living in standard dilution water[2].
2. Two fish are to be used per test.
3. Test fish are not to be used for more than one test during their lifetime.
4. A minimum of one litre of the test water is required.
5. The test water container is to be of glass and of a minimum capacity of approximately two litres.
6. A control test is to be carried out (using standard dilution water) simultaneously with the actual sump fluid test.
7. Dissolved oxygen in the contro and test jars is to be maintained at a minimum of eight milligrams per litre.

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[1] Standard methods for the examination of water and waste water. Thirteenth edition 1971, APAJ, AWWA, WPCF. Americal Public Health Association, 1015 - 18 Street N.W., Washington, D.C. 20036.

[2] Standard dilution water:

For every 10 imperial gallons of demineralized water, add the following reagent grade chemicals:

1. 4 grams $CaSO_4 \cdot 2H_2O$
2. 4 grams $MgSO_4 \cdot 7H_2O$
3. 1.5 grams $CaCl_2 \cdot 2H_2O$
4. 3 grams $NaHCO_3$
5. 0.2 grams KCl
6. 0.125 grams $Ca(OH)_2$
7. 0.125 grams $Mg(OH)_2$

ENERGY RESOURCES CONSERVATION BOARD

Calgary, Alberta

Interim Directive
ID 81-1

TO: ALL OIL AND GAS OPERATORS

SUBSURFACE DISPOSAL OF DRILLING FLUIDS

This Interim Directive supersedes Interim Directive ID 70-3 issued on 15 December 1970.

The Board will permit operators to dispose of drilling fluids not only in dry holes, but to any well where subsurface disposal of drilling fluids is feasible.

The Board believes that under appropriate constraints the subsurface disposal of drilling fluids can be carried out without jeopardizing any subsurface potable water horizons. It will consider such disposal as part of the drilling or completion program for a well and separate approval under section 38 of The Oil and Gas Conservation Act will not be required. The subsurface disposal of drilling fluids may be carried out subject to the following conditions:

1. Permission of a Board representative shall be obtained before any disposal operation is commenced.

2. The disposal zone shall be at a depth not less than 600 m.

3. The resistivity directly aptributable to the total natural dissolved solids in the FORMATION WATER of the disposal zone shall be less than 0.33 ohm.M corrected to 20°C (equivalent to 20 000 ppm total dissolved solids).

4. The disposal zone shall be known not to contain hydrocarbons within two kilometres of the intended disposal well.

5. Where a well is to be abandoned or plugged back, and does not contain at least 600 m of casing cemented in place:

    (a) the disposal of fluids shall be through drill pipe and below a seated packer, and

    (b) the annulus between the drill pipe and the surface casing shall remain open to the atmosphere during any disposal operation.

6. Where a second casing string has been run in a well and not cemented to surface:

   (a) the disposal of fluids shall be through the annulus between the casings, provided the surface casing is deeper than 600 m,

   (b) the disposal zone shall be identified by depth and geological designation,

   (c) the fluids to be disposed shall be displaced out of the annulus with inhibited fluid. If, after displacement, pressure exists in the annulus, cement shall be displaced into the formation to seal off the disposal interval, and

   (d) the annulus shall be left open to the atmosphere in the manner described in subsection 6.100(2) of the Oil and Gas Conservation Regulations.

7. Where the disposal zone has been cemented behind casing:

   (a) the disposal zone shall be identified by depth and geological designation,

   (b) the casing shall be perforated and the fluids disposed of through the perforations, and

   (c) the perforations shall be appropriately sealed or isolated.

ISSUED AT Calgary, Alberta, on 12 March 1981.

ENERGY RESOURCES CONSERVATION BOARD

V. E. Bohme
Board Member

TOXICITY TESTING AND LABORATORY PROCEDURES FOR ANALYSING AND EVALUATING DRILLING FLUIDS

D.R. Shaw[1]

Twenty years ago it seemed that little was known about the toxicity or lack of it, not only in drilling fluids, but in sump fluids and many chemicals. Metallic wastes and even brine were not well understood. I read much of the published data at that time and I was impressed with two points:

1) the complexity of the apparent toxicity of drilling fluids, and
2) the lack of quality in the published data.

I, therefore, sought out local biologists, zoologists, entomologists, botanists, etc., and finally came to the conclusion that everyone had different ideas based on different criteria obtained under different circumstances. Therefore, one was still left with the need to question:

1) how low a level of various materials would kill or damage animals, insects, or plants?
2) what is the difference between hard and soft water that so affects the results of tests performed in hard or soft water?
3) how hard must a water be in order for it to be effective in acting against, or with, toxicity?

Defining toxicity as that concentration of a substance that kills in a short time might be far too simplistic since people were beginning to place considerable emphasis on Max Katz' work relating the concentration of toxic component necessary to kill half the test organisms by a particular time limit.

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[1] Chief Chemist, Energy Resources Conservation Board, Calgary, Alberta.

EXAMPLE: LC_{50} at 96 hours

In order to clarify, it was decided to set some standards - however temporary or erroneous, one had to start somewhere. So, very simple criteria were applied to assess the quality of sump fluids that were to be disposed of to the lease area or off it. These criteria were:

1) if the chloride concentration was less than 500 mg/L the off-lease disposal could be permitted.
2) if the pH was also somewhere between 6 and 8 then it would be assumed that there would be no problem generated by off-lease disposal.

It is quite evident that one would still be concerned since quite toxic material could easily fall within this category. I, therefore, talked to Paul Paetkau who was then employed by the Fish and Wildlife Division of Alberta Energy and Natural Resources and asked him if he knew of any test for toxicity that he could apply somewhat like the work done by Dr. Katz. He volunteered to test any sump fluids that I brought to him by putting in whitefish fry that were being raised in their laboratory. When the tests began, he used rainbow trout rather than the eyed-eggs of the whitefish. After many tests, we noticed that some sumps having less than 1 ppm of chloride were very toxic and one as high as 17 600 ppm chloride was not toxic in the 96 hour test.

We, therefore, showed that toxicity was not directly related to these two parameters, but that other factors were involved. We also concluded that we should begin testing the individual components of drilling fluids to see if we could not determine their toxicity. Unfortunately, we were then stymied by references in the literature concerning the test results obtained when using hard or soft water. Everyone seemed to contradict everyone else. Would tap water, de-chlorinated tap water, or distilled water have to be used to make up the necessary solutions? Only one thing seemed to be apparent: that not much work has been done using distilled water, and that the quality of the Edmonton city tap water varied widely with the seasons.

When distilled water from an automatic continuous still was used, it was usually found to be quite toxic. But when a batch of water was distilled and the first quarter of distillate was discarded as well as the last quarter, the middle half tested out as okay for the trout. It shortly became evident that when one steam distills a batch of mixed chemicals, some of which are chlorinated organics, some will be distilled over with the steam - a routine separational technique in organic chemistry. More checking convinced us that in order to obtain pure test water we would have to use ion-exchange resin beds, charcoal, and particulate filters. Eventually, we generated 12 million ohm test water. The zoologists then told us that although the material in the water would not kill the fish, the fish would still die because they would depurgate, or lose their essential ions into the water. They were right, but wrong in how quickly this would occur: it took 30 days.

So we felt that we could use such water for testing dilutions of chemicals for four days without much interference from the water.

Now we began to test the components used in drilling fluids and commonly found to some extent in drilling sump fluids. The simplest of these components seemed to be the chloride ion; how toxic was it? Unfortunately one cannot test a single ion as all negative ions are exactly balanced with positive ions and for tests like these you could not use all negative ions or all positive ions. We therefore decided to test the common salts of sodium beginning with sodium bicarbonate and sodium chloride (baking soda and table salt respectively).

A number of mono-valent salts were tested:

$$\left.\begin{array}{l}\mathrm{NaHCO_3}\\ \mathrm{NaCl}\\ \mathrm{Na_sSO_4}\\ \mathrm{NaMO_3}\\ \mathrm{NaOAc}\end{array}\right\}$$

... All showed nearly the same degree of toxicity when dissolved in the 12 megohm water

Any concentration of the sodium ion above 20 ppm was lethal. We repeated this with potassium salts, obtaining much the same results, except that they were a little more toxic since over 15 ppm of potassium was lethal. Finally we tried the calcium salts and found that the fish could stand up to about 20 000 ppm calcium ion and about 15 000 ppm of the magnesium ion. We further found that when sodium at 1 000 ppm was mixed with the calcium or magnesium ion, even if they were all chlorides, that the fish could survive.

Subsequently we were told by the cell specialists that the divalent ions of calcium and magnesium protect the cell wall barrier against the passage of the monovalent ions.

We have found that if the sodium and potassium salts in a sump fluid do not exceed 1 700 ppm of sodium and potassium combined that we could expect survival as long as there was a reasonably high concentration of calcium or magnesium, or both, present. This realization caused us to develop a testing program for saline fluids that would make it possible to know whether a saline and toxic sump was toxic due to the salinity or to the organic content.

> **EXAMPLE:**
>
> If the chloride concentration is 5 700 mg/L then a 1:2 dilution would give a chloride concentration of 1 900 mg/L of chloride ion. A 1:3 dilution would give a test solution of 1 425 mg/L. If this 1:3 dilution still killed fish, in spite of the toxic organics being diluted, we could then conclude that some of the organic material in the sump fluid was responsible for the trout death. We could also advise the operator to reduce the hazard by an appropriate treatment to generate a fluid which would pass the trout check prior to disposal.

A further question may arise when one considers that trout do not live outside the laboratory in demineralized water. To answer the obverse of this question, 28 southern Alberta trout steam waters were analysed and averaged to produce a recipe for "synthetic trout stream water". One fish was grown in a tank of this water for a period of one year. So we remineralized our trout stock tank water with a mixture of reagent-grade chemicals giving water of the standard trout stream variety.

This should give us a standard dilution water for a standard dilution test using standard trout.

We often run sump fluid dilutions using this water together with dilutions using demineralized water and have found good agreement between the two methods, perhaps largely due to only running the tests for four days. This has been done for many chemicals used in the drilling industry and includes checking unused mixtures as well as the used mixture known as a sump fluid. By this means we can ascertain the possible impact of such materials on the environment.

When dealing with sump fluids minimally toxic, i.e. pass the 96 hour test, saline fluids can be generated and in spite of the pass generated in the trout check, the undiluted saline fluid can be a problem for disposal. After some careful checking by the Department of Agriculture, we have developed a rough rule for disposing of saline fluids and have found that when it is applied to "pass trout check" fluids that were saline, then little or no vegetative damage is apparent. The rule for such fluids has been for every 1 000 mg of chloride present each 1 000 barrels of fluid will need an acre of ground for disposal.

Consideration of the results of this type of testing has caused the Board to issue directives concerning the method of collecting, testing, and disposing of sump fluids, setting forth the criteria which the operators have agreed to follow in disposing of such fluids. These criteria are under review and will be altered in accordance with the findings, but only when they and the industry are convinced that the data are correct.

The analysis of sump fluids can be quite difficult because the very nature of the fluid can make it impossible to separate the water from the suspended solids by filtration. Some of the evaluative procedures can be performed on the whole fluid, some require clear fluid and a choice of flocculent which will not affect the particular parameter being examined but will make it possible to filter out some clear water. In this way it is possible to measure the salinity, pH, toxicity, etc.

Toxicity can be determined by immersing live trout in the fluid or in dilutions of the fluid. There are other organisms in use for toxicity testing such as a goldfish, the fathead minnow, mosquito fish, guppies, daphnia, may flies, or even bacteria, or algae. One recent development has been "mechanized" by Beckman Instruments and is called the microtox toxicity analyser. This method utilizes photo-luminescent bacteria. The principle behind the idea assumes that reasonably happy bacteria of a special type will luminesce. If they are made unhappy by immersion in damaging material then they will stop luminescing. We have found good agreement with the live trout check: about 75-80% correlation. The reasons for disagreement are quite complex and probably should not be examined at this meeting.

Another method of examining effluents using nematodes has been developed by Dr. M. Samoiloff at the University of Manitoba and we are seeking to evaluate its meaning and usefulness in relation to sump fluid testing.

Today you should probably hear about some modern trends in drilling, one of which is the development of KCl systems. However, one should be careful in assessing the need for such systems because they may be used in this province and elsewhere to overcome problems generated by using bentonite that consists of bentonite treated with soda ash and a polyacrylamide material. This used to be called "peptized bentonite", but now is called treated bentonite. Bentonite alone is not immediately dangerous to fish except at quite high concentrations on a long term basis. However, the peptized material does contain materials which make it many times more toxic to fish than the unpeptized or untreated bentonite. This treated bentonite "yields", giving a considerable viscosity to both the bag mix and to any bentonite-like material encountered during the drilling operation. The result can be mud rings in the hole, etc. To overcome this, KCl fluids are used which cause the bentonite encountered to "shrink", disperse, or otherwise not generate mud rings, etc. Hole problems are then eliminated.

Unfortunately, both the KCl and the additives produce quite toxic drilling fluids that can be quite difficult to treat when they are disposed of and become part of the sump contents. It is highly probable that the KCl systems have saved money in the drilling operation. However, they have been rather costly to dispose of in an ecologically safe manner. The answer should probably be to use fluids and components that are minimally toxic to start with and that remain so right through to completion of drilling and through lease cleanup.

Paradoxically perhaps, it should be possible to both drill a better, cheaper hole and still have waste materials that have little or no impact on the environment.

Unfortunately, in our complex society, we tend to generate complex waste products. We must learn to be careful not only of what we generate but of how we dispose of those wastes.

ALBERTA'S MAJOR DRILLING MUD SYSTEMS AND THEIR COMPOSITION

Dr. H.U. Ziedler[1]

INTRODUCTION

The implementation of rotary drilling practices in the search for hydrocarbons necessitates the use of a circulating fluid commonly referred to as drilling mud. The subsurface geological environment, the imposed drilling practices and the many functions a drilling mud must perform, results in numerous different mud systems, and consequently products or additives that are being used today.

This report shall not deal with all mud products or systems specifically. Rather, it will present mud systems as general classes and deal with the families of additives (products) used and the reasons for their use in each mud system type. Before dealing with mud systems themselves, a brief discussion on drilling mud functions is provided.

1. DRILLING MUD FUNCTIONS

1.1 Particle Removal

For an efficient drilling operation a drilling mud must be able to remove the bit cuttings away from the wellbore face as they are being generated by the drilling bit. Once the particles are removed from the face of the wellbore the drilled particles (cuttings) and any particles which may fall into the wellbore from its walls (cavings) must be transported to the surface for removal. Rheological properties (e.g.,

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[1] National Mud Control Laboratories, Calgary, Alberta.

viscosity), fluid density and velocity are the primary factors related to particle removal.

1.2 Wellbore Stability

In the absence of casing, a drilling mud must be capable of "holding up the wellbore well" and preventing the intrusion of formation fluids while drilling.

Wellbore instabilities are usually of a physical or chemical nature. Physical instabilities arise from regional or local tectonic stress fields (e.g., from faulting, folding, uplift, etc.), high formation fluid pressures, lithology and poor drilling practices. Chemical instabilities arise as a result of the interaction of the surface chemistry of the formations being drilled with the electrochemical (ionic) nature of the drilling muds liquid phase (its filtrate).

Physical instabilities are normally controlled by drilling mud density while chemical instabilities are controlled by "inhibition" (providing a certain ionic state or chemical balance in the filtrate) or the minimization of filtrate invasion into the formations being drilled.

1.3 Wall Building Characteristics

Regardless of the magnitude of formation permeability, when a positive pressure differential exists between the wellbore hydrostatic pressure and the formation pore pressure the drilling mud will permeate into the formation. In so doing all or a part of the solid phase of the drilling mud is left behind and deposited as a "filter cake" on the wellbore. The thickness, texture, compressibility and permeability of the filter cake play an important roll in providing formation stability (both physically and chemically), minimizing downhole drilling problems such as differentially stuck drill strings and excessive torque and friction on the drill string, especially in deviated (non-vertical) holes.

Wall building characteristics, i.e. thickness, texture compressibility and permeability, are usually controlled by the addition of "fluid loss reducers". Most additives for controlling wall building characteristics are covered by this term since such additives usually result in the reduction of fluid (filtrate) loss to permeable formations.

1.4 Cooling and Lubrication

Considerable heat is generated by friction and energy transport at the drill bit and at points where the drill string contacts the wellbore wall. As a coolant drilling mud can convect heat away rapidly from points of high heat generation and as a lubricant, lubricity can be enhanced in the drilling mud itself, e.g., addition of oil, or in the filter cake.

2. THE GENERAL CLASSIFICATION OF DRILLING MUDS

Any drilling mud can be thought of as a two phase solid-liquid or gas-liquid provided that the solid phase is restricted to those solids which are recirculated. Air, mist, foam and stiff foam drilling fluids comprise the gas-liquid systems and are not considered herein. In the solid-liquid system the liquid phase itself can take on a variety of forms which are differentiated on the basis of the continuous portion of the liquid phase.

a) Water Based Mud Systems:
  - water is the continuous phase
    i) fresh water
    ii) saline water
    iii) Oil emulsified in fresh or saline water

b) Oil Based Systems:
  - oil is the continuous phase
    i) "oil" only, e.g., crude oil, diesel oil or mineral oil
    ii) fresh or saline water emulsified in the oil

Only the water based solid-liquid systems are discussed further.

2.1 Water Based Drilling Muds

2.1.1 Native Muds

These muds use water only and rely on the drilled formation solids to provide the viscosity, if necessary, for adequate particle removal. They are susceptible to wellbore instabilities, formation damage and downhole drilling problems. Consequently native muds are restricted in use to shallow surface holes or the upper portion of the main hole interval of shallow holes typical of southeastern Alberta, and many other areas east of the fourth Meridian.

Chemical additives in native muds are restricted to very low concentrations of sodium acid pyrophosphate (in the order of 0.05 kg/m^3) for the control of mud rings and on rare occasions minute amounts of lime are added to provide temporary viscosity increases.

2.1.2 Clear Water Drilling Fluid

To maximize penetration rates it is desirable to drill with clear water. This can be accomplished by flocculating and settling out the drilled solids in the mud tanks or by circulating the sump.

Flocculation of the drilled solids is accomplished by the use of lime and calcium chloride in conjunction with a flocculating polymer. Lime additions are normally made to provide and maintain a pH in the 10-11 range while calcium chloride is added only as required to maintain a clear water at the mud pump suction. The flocculating polymer (usually a polyacrylamide) is added as an adsorbant in conjunction with the lime and calcium chloride.

A typical clear water drilling fluid would have the following chemistry:

pH: 10-11
Ca: 100-200 mg/L
Cl: 800-1 500 mg/L
Polymer Content: very low (mostly adsorbed onto the solids)

Clear water drilling is common to the plains and foothills of Alberta and can be accomplished with success below the surface casing to depths of 1 500-2 200 m.

In some areas of the plains and foothills in order to prolong the clear water drilling program the calcium chloride is replaced by potassium chloride in order to reduce the susceptibility to swelling of the water sensitive shales and shaly sands commonly encountered in tertiary and cretaceous sediments. The inhibitive clear water drilling fluid will have a potassium and chloride concentration each in the order of 10 000-20 000 mg/L.

2.1.3 Bentonite (Gel) Viscosified Mud

The bentonite viscosified drilling mud is the basis of many of the water based mud systems used throughout all of Alberta.

In its very basic form this mud contains bentonite (sodium montmorillinite or gel are other common names) in concentrations of 35-70 kg/m^3, as the viscosifier, caustic soda to a pH of 9-10 promotes the yielding of the bentonite and provide minimal protection against corrosion, and carboxymethylcellulose at a concentration of 1-3 kg/m^3 for fluid loss control.

In the absence of high drilled solid concentrations and other contaminants such as anhydrite (anhydrous calcium sulphate), sodium and/or calcium chloride (salt formations or salty water), carbonate or bicarbonate ions, and hydrogen sulfide gas this mud could be used to drill anywhere provided mud density requirements and temperatures are not excessive and water sensitive formations are not exposed for a prolonged period of time.

2.1.4 Extended Bentonite and Water Viscosified Polymer Muds

Increasing the viscosity of a mud by the addition of more bentonite alone can lead to several undesirable characteristics of a drilling mud including an increased susceptibility to chemical contamination and the susceptibility to the build-up of undesirable drilled solids which results in increased mud density (hence slower penetration rate) and uncontrollable rheological properties (abnormally high viscosities).

2.1.4.1 Extended Bentonite Muds. One method of increasing the viscosity of a bentonite viscosified mud is by the addition of a polymer to extend the yield of the bentonite being used (hence the name extended gel systems). With the use of the polymer (usually a form of polyacrylamide in a 1:200-300 w/w ratio with the bentonite), significant increases in the low shear rate viscosity of the drilling mud can be realized that would otherwise require the addition of significant amounts of bentonite.

In its simplest form the extended gel system is otherwise the same as the bentonite viscosified system.

2.1.4.2 Bentonite - Water Viscosifying Polymer Muds.

Polymers alone as viscosifiers in a drilling mud have had relatively little success. However the use of water viscosifying polymers in conjunction with bentonite is the basis for very successful mud systems wherever a low solids and higher viscosity environment are required. The reason for their success is cost effectiveness and the secondary functions (such as fluid loss control and limited but improved inhibition) that the polymers provide in a truly low solids, low density environment.

The water viscosifying polymers commonly used are xanthan gums, guar gums, carboxymethylcellulose (hi-vis), polyanionic cellulose, hydroxyethylcellulose and polyacrylamides in concentrations of 1-5 kg/m^3.

For the water viscosified mud systems the bentonite concentration is reduced to 20-40 kg/m^3, the pH is still maintained in the 9-10 range and other fluid loss reducers such as polyacrylates are also used.

2.1.5 Saline Water Based Mud Systems

Although one may associate chlorides with the word salinity, in drilling muds this is not necessarily true. The use of inhibitive muds is primarily restricted to areas where water sensitive formations are exposed for prolonged periods of time, e.g., deep foothills wells, or where water sensitive producing formations are encountered and costly completion practices are desirably minimized or eliminated. Alternately in areas where salt water flows (usually mixed salts of sodium, calcium and magnesium chloride) are common or where rock salt is encountered while drilling a mud system must be salt saturated (or nearly so) to prevent dissolution of the formation and to provide a rheologically controllable drilling fluid.

The salts commonly used in inhibitive (to water sensitivity) muds are potassium chloride (20 000-40 000 mg/L), potassium sulphate (10 000-30 000 mg/L) and diammonium sulphate (10 000-20 000 mg/L). In salt saturated mud systems sodium chloride is commonly used with fresh water or as a supplement for natural brine waters if they are available.

The most common saline inhibitive mud system is the KCl-polymer mud system. For viscosity requirements fresh water, prehydrated bentonite is used in concentrations of 15-35 kg/m^3. The viscosity is derived from the flocculation of the prehydrated bentonite in the presence of the potassium chloride in the drilling mud's water phase. In this highly flocculated state the drilling mud has an extremely high fluid loss and thick, mushy filter cake. Consequently, deflocculants such as polyanionic cellulose, polyacrylates and xanthan gums (which are viscosifiers in fresh water or the absence of flocculated gel) are used in total polymer concentrations of 1-3 kg/m^3 to reduce the fluid loss and provide a thinner and firmer filter cake. For enhanced inhibition in some muds, a partially hydrolyzed polyacrylamide is used in concentrations of 0.5-1.5 kg/m^3.

The salinity level (20 000-40 000 mg/L) required for inhibition is highly corrosive so most of these muds added maintain an alkaline pH of 9.5-10.5 with caustic soda and use an oxygen scavenger (ammonium bisulphate or catalyzed sodium sulphite) with sulphite concentrations of 200-300 mg/L being quite common.

The ammonium or saturated salt systems are normally run with a near neutral pH. They may use prehydrated bentonite, attapulgite or polymers such as xanthan gum or polyanionic cellulose as viscosifiers.

For fluid loss control in all saline based mud systems starch is sometimes used. It is more common is salt saturated mud systems and often (although not always) a preservative such as paraformaldehyde or other biocide in concentrations of 0.3-0.7 kg/m^3 is used.

3. THE TREATMENT OF WATER BASED DRILLING MUDS

In the absence of contaminants and unforeseen, geologically imposed drilling problems, the basic mud systems described could virtually drill a well anywhere in the world and the treatment of drilling mud would be reduced to a maintenance program under a prescribed set of preplanned conditions. However, as always, Mother Nature has her way and enters into the picture in the form of contaminants, underground rivers or caverns, abnormally high, or low, formation pressures, crumbly, incompetent formations, and extreme geological structures that can turn a planned vertical hole into a corkscrew.

Contaminants are a way of life in a drilling mud system. Generally speaking in their chemical form they are dissociated ions that enter into the mud system from the formations or the formation waters as they are being drilled. Together with undesirable drilled solids (fines that cannot be economically removed), contaminants in general disrupt the planned or desired rheological properties of the drilling mud. If contaminants are allowed to persist they may lead to excessive viscosities that could make the mud unpumpable or break down formations that may eventually lead to abandonment of a well.

Further, air or gas can turn a drilling mud into an unpumpable foam, hydrogen sulfide can embrittle steel and endanger the lives of drilling crews, stubborn non-hydrocarbon bearing formations may result in prohibitive drilling costs to achieve the depth of the hydrocarbon bearing formation and abnormally high formation pressures can easily result in a blowout.

Drilling mud treatment deals with these kinds of problems. For the purpose of this reort we shall subdivide the treating chemicals or drilling mud additives into groups of primary functions they are intended for and the mud systems they are applicable to.

3.1 Calcium, Carbonate, Bicarbonatre and pH Control Additives

Many additives are active only in a basic environment. Most drilling muds are more stable in an environment having free hydroxyls and the absence of bicarbonate ions. Compounds commonly used are:

i) sodium hydroxide - to raise and maintain pH, or reduce bicarbonates to carbonates.

ii) potassium hydroxide - sometimes used for pH control in KCl muds.

iii) calcium hydroxide - for raising or maintaining pH and reducing carbonate content.

iv) sodium bicarbonate - to lower pH and reduce the calcium concentration (e.g., cement contamination).

v) soda ash - to reduce carbonates.

vi) barium carbonate - seldom used for the control of calcium because of cost and toxicity by ingestion.

3.2 Bactericides

Bactericides are not common to most mud systems. Only where starch is used, e.g., salt saturated muds and rarely where xanthan gums are used (water viscosifying polymer muds), will bactericides be prevalent. The most common bactericide is paraformaldehyde. Other biocides have been incorporated from time to time.

3.3 Corrosion Inhibitors and Scavengers

The primary sources of corrosion in a drilling mud are dissolved oxygen, carbon dioxide, scale and hydrogen sulfide.

i) oxygen corrosion - ammonium bisulphate and catalyzed sodium sulfite are the most common oxygen scavengers. They are used primarily in saline water based systems.

ii) sweet corrosion (carbon dioxide) - it is seldom detected. It can occur as a result of carbon dioxide entrapment into the mud from the air or in formation waters existing as CO_3 and HCO_3. Control is usually achieved by the addition of sodium hydroxide or lime, i.e. by maintaining hydroxyls in solution in the mud's liquid phase.

iii) scale - scale can occur in a high calcium, high pH and high carbonate environment. It is usually detected as a scale build-up on oil field tubulars. Scale inhibitors are commonly in the form of blended water soluble organic phosphates.

iv) hydrogen sulfide - hydrogen sulfide corrosion is common to all the sour gas areas of Alberta. As scavengers ferro ferric oxide and varieties of zinc compounds such as zinc carbonate and chelated zinc are used and for inhibition, film forming amines are used.

3.4 Defoamers

In any drilling mud, foam can result from the entrapment of air into the mud from the mud surface equipment, e.g., shale shakers, hydrocyclones, mixing hoppers, etc., or from the intrusion of gas from the formation. Excessive foam or entrapped air can make a mud unpumpable and also, it may sufficiently reduce the hydrostatic pressure of the mud column thereby increasing the potential for a blowout. The most common defoamers are aluminum stearate, various alcohols and sulfonated oils.

3.5 Lubricants

Generally speaking lubricants can be used in any mud system and are restricted to areas where crooked holes (the foothills) or directional holes (the foothills or areas of restricted access and heavy oil recovery projects) are being drilled. Lubricants are primarily used to reduce the friction that can occur wherever the drill string make contact with the hole wall. The most common friction reducers are:

i) diesel or crude oil in concentrations of 3-12% by volume.

ii) graphite, glass beads or walnut hulls in a concentration of 3-6 kg/m^3.

Also, when a drilling string becomes differentially stuck a "spotting fluid" is incorporated into the mud system to help free the stuck drill string. The spotting fluid is primarily diesel oil containing 0.05-0.1% by volume of various organic surface-active agents and sulfonated oils. After use, the spotting fluid is sometimes passed directly to the sump or mixed into the entire mud system.

3.6 Shale Control Inhibitors

Other than the inorganic salts (e.g., KCl), a variety of polymeric and organic shale inhibitors can be incorporated into any water based drilling mud. These include pure gilsonite, blown asphalt, sulfonated asphalt and partially hydrolyzed polyacrylamides.

3.7 Thinners (Dispersing Agents or Dispersants or Deflocculants)

The effect of drilling into contaminants such as calcium, sodium is similar to the result obtained from the gradual increase of undesirable fines (drilled solids) that are naturally incorporated into a mud system as drilling progresses. In general this will cause an undesirable increase in the viscosity and thixotropy of the drilling mud. The contaminants create large increases in the low shear rate viscosity and thixotropy of the drilling mud whereas drilled solids increase the thixotropic characteristics (the ability of the mud to gel when it is at rest) and the viscosity over the entire shear rate range of the drilling mud. If these increases are not controlled the consequences can be excessive circulating pressures, unpumpable mud, formation breakdown, further increases in drilled solids content, reduced penetration rate, and stuck drill strings which may eventually result in abandonment.

Dispersants can be added to a mud system to reduce its low shear rate viscosity by reducing the effect of the contaminant, by substituting favourable for unfavourable ions on the clay particles, or by forming a protective film around the clay particles. The various forms of dispersants that can be found in any fresh water based mud system are:

i) phosphates - e.g., sodium acid pyrophosphate, sodium hexametaphosphate and sodium tetraphosphate. These are very powerful dispersants usually used in concentrations of $0.5\ kg/m^3$ or less. They are restricted in use to muds whose temperature does not exceed 80°C and because of their acidic nature are seldom used without increased additions of sodium hydroxide. Their ability to lower viscosity is related to neutralizing attractive forces by being adsorbed on the surface of solids and by sequestering or tying up calcium or magnesium. Phosphates are generally not effective at high salt concentrations.

ii) tannins - tannins like phosphates are rarely used without the addition of sodium hydroxide to neutralize the acidic nature of the tannin. Tannins work best in high pH muds and besides lowering viscosity, they produce exceptional filter cakes. Tannins are not effective at high salt concentrations or in high calcium environments.

iii) lignite - lignites are not strong dispersants that behave the best in low pH, low calcium and salt concentrations. They are sometimes found as chrome lignite or in a precausticized form. They are more commonly used in conjunction with other dispersants such as lignosulfonates.

iv) lignosulfonates - these are metallic sulfonate salts that are commonly found as chrome or ferrochrome lignosulfonates. Lignosulfonates require a basic environment (pH greater than 9.0). They are effective in high calcium and salt environments for temperatures below 120°C and besides lowering viscosity and gel strength, when used in sufficient quantities, it reduces fluid loss and creates an inhibitive environment.

The concentrations of tannins, lignites and lignosulfonates vary from 6-25 kg/m^3. Commonly, concentrations are in the 15 kg/m^3 range.

3.8 Weighting Materials

In an environment of normal pore pressure gradients and tectonically relaxed stress fields it is desirable to drill with low density drilling muds. However, when abnormally high formation pressures or regional or local stress fields are high, it is necessary to resort to increased mud densities. Failure to increase mud density can result in blowouts and/or severely unstable well bores, either of which are costly drilling problems to contend with.

By far the most common weighting agent is barite (barium sulfate). In its pure form it is inert and has a high specific gravity thereby enabling density increases with minimal increases in the drilling muds solid content. In extreme cases, for very high density requirements (relatively uncommon to Alberta) hematite or galena are used. The use of calcium carbonate or dissolved salts such as sodium or potassium chloride as weighting agents is rare in drilling fluids but more common in completion fluids.

TREATMENT AND DISPOSAL OF WASTE FLUIDS FROM ONSHORE DRILLING SITES

G.A. Specken[1]

ABSTRACT

The accumulation and storage of waste materials in open, earthen pits (sumps) during the drilling of onshore oil and/or gas wells leads to an appreciable volume - up to 100 000 barrels per site - of waste fluids of varied composition. Disposal of these sump fluids has become a problem in those parts of the country where regulatory bodies no longer allow simple dumping of the fluids to the environment. For instance, in Western Canada the clarified water from drilling site sumps must meet certain quality standards, primarily the passing of a trout bioassay, before it can be pumped off-lease. A process has been developed whereby the sump contents are treated in-situ such that a major portion of the total fluid volume is generated to the land. A minor portion of the total fluid volume is left as wet, flocculated solids or sludge in the bottom of the sump pit for burial there or disposal to the lease area. The various aspects of this treatment and disposal process are discussed, and cost data for two years of commercial operation in Western Canada are presented. In some selected cases, the cost data are related to the types of drilling fluid systems used to drill the holes.

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[1] Spectra Water Processes Limited, Edmonton, Alberta.

TREATMENT AND DISPOSAL OF WASTE FLUIDS FROM ONSHORE DRILLING SITES

G.A. Specken[1]

INTRODUCTION

In order to appreciate various aspects of the treatment and disposal of waste fluids from onshore drilling sites, a brief examination of past and present practices in Alberta in this regard is helpful.

During the drilling of an onshore oil and/or gas well, an open earthen pit or sump is used as a collecting basin for waste drilling fluid, solid cuttings from the hole, and wash water from the drilling rig deck. Because the pit is open to the atmosphere, the sump contents are increased or decreased by whatever net precipitation that happens to occur. By the end of a drilling operation, an appreciable volume (typically 5 000 to 50 000 barrels, and occasionally as much as 100 000 barrels) of waste fluids has thus accumulated in the sump. Generally, sump contents consist of three distinct phases - a thin layer of oil scum on the surface, a large aqueous phase with dissolved components and suspended solids, and a bottom layer of sludge containing most of the solids which have settled.

Until recent years, it was normal practice in Alberta to dispose of the contents of drilling site sumps directly to the environment, that is, to the lease and surrounding area without prior treatment whatsoever. If the oil scum was inflammable, it was not uncommon to concentrate it at one end of the sump and burn it. The so-called "clear water" layer was pumped out of the pit and distritued over the lease or adjacent area to dry to atmosphere or soak into the ground. The partly empty pit was then filled in by bulldozing brush and earth into it. In doing so, the sludge layer was either buried, or "squeezed" out of the pit and spread on the lease surface to dry or to be worked into the topsoil.

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[1] Spectra Water Processes Ltd., Edmonton, Alberta.

In recent years, public and governmental concern over environmental pollution led to more stringent requirements than those outlined above for the disposal of these waste fluids. By the early 1970s, there was a significant number of cases in Alberta where the sump fluid in question was considered environmentally hazardous and it had to be hauled away and disposed of in some designated location, such as a gravel pit or a disposal well. The high haulage costs and the long time delays for the total lease cleanups pointed out the need for a better disposal method for these "problem" sumps. Consequently, in mid 1971, Wilson Mud Service Ltd. initiated a research project to achieve this end.

DEVELOPMENT OF THE TREATMENT PROCESS

The ultimate objective of the research project was to develop a process by which drilling site sump fluids could be altered so that they could be disposed of directly and safely to the environment. Under the project, it was proposed to evaluate various water and waste water treatment methods and apply them to drilling site sump fluids in the context of remote drilling locations.

For the project evaluation, the total process was divided into three areas of investigation, namely oil-water separation, solids-liquids separation, and purification of the clarified water phase to render it sufficiently innocuous to the environment. Consideration of the various constraints imposed by the drilling site context led to a specific list of known treatment methods to be evaluated in each area of investigation. Although these proposed methods were part of existing technology, the various aspects of the drilling site context - remote location of leases, seasonal weather conditions, complex and variable sump composition, and diversity in water quality required by regulatory bodies - suggested that existing treatment methods would require some adaptation and innovation.

The various candidate processing steps were first screened for technical and economic feasibility by conducting paper engineering studies supported by experimentation, where necessary, on actual problem sump fluids. At the outset, it was evident that only batch type processes or treatment steps that could be effected in the sump were the most promising candidates. Also, a relatively small scale of testwork - batch charges of a quart to a gallon each - was found satisfactory for evaluation of certain steps (such as coagulation-flocculation, adsorption, precipitation and oxidation). This was because the efficacy of these techniques is usually predictable, provided that adequate mixing and/or contacting with the test fluid is achieved. The importance of this small scale development work is emphasized, because it led to full scale field tests without intermediate scale-up.

The experimental program involved as large a variety of actual problem sump fluids as possible, so that the resultant process would be versatile enough to cover the majority of problem sumps, if not all, when commercialized. It was anticipated that one water treatment method would be insufficient to cover the range of pollutants known to exist in sump fluids, but it was intended to engineer all the chosen techniques into one equipment assembly. This was borne in mind when selecting the various treatment methods, most of which can be effected by pumping and mixing some ingredient into the sump contents.

On the basis of the engineering studies and the bench scale experimentation program, the most promising candidate processing steps were translated into a prototype field equipment assembly, which as then used to conduct a field test program. After five successful field tests, a follow-up evaluation of the process and the prototype unit was carried out.

In both the bench scale experimentation program and the field test program, samples of treated and clarified water from each experiment were evaluated in terms of water quality by the test(s) that would be used by the pertinent regulatory bodies in a real disposal situation. In Alberta, the main water quality test, developed especially for this purpose, is a modified fish bioassay using rainbow trout. Therefore, the treatment process was designed primarily to transform a maximum amount of a given sump fluid into clarified, detoxified water that passes a trout bioassay.

COMMERCIAL APPLICATION OF THE PROCESS

The process that evolved from the above research project has been applied commercially in Alberta during the operational seasons of 1973 and 1974, and to a lesser extent in British Columbia in 1974. An operational season is generally limited to the time between spring thaw and fall freeze-up, but has been extended a month or so beyond freeze-up by using heating equipment to melt ice caps or keep them from forming on the sumps while the various steps of the process are underway.

A rather methodical approach is taken in the commercial appliclation of the process. For a given sump, this involves a series of activities that include a prior sump evaluation, a cost projection and contract bid, and the actual field treatment and disposal of the fluid.

1. Sump Evaluation

In order to ensure that a given sump can be treated successfully and disposed of at a predictable cost, a complete evaluation of it is carried out. This evaluation takes place both at the sump site and in the laboratory.

First, the location is visited to obtain direct information on the sump, the lease, and the surrounding area. The surface dimensions of the sump are measured. Using a boat to traverse the surface of the sump, depth measurements are taken (by probe or weighted string) from various points so as to estimate both the average total depth of fluid in the sump and the average thickness of the mud layer in the bottom of the sump. Similarly, with the boat located at different points on the sump surface, fluid samples are taken from different elevations in the sump. The existence and approximate volume of oil layer are noted, as well as the relative degree of solids suspension in the fluid body. Finally, a visual appraisal is made of the lease access road, the surface condition of the lease, and the surrounding area. This helps to predict what mobility problems might be encountered, and also indicates where the service rig could be located next to the pit and where the treated water could eventually be pumped.

The laboratory evaluation involves lab treatment of the sump samples to determine the proper sequence and dosages of chemicals required for successful toxicity reduction and clarification of the sump fluid. The efficacy of each treatment program thus determined is verified by trout bioassays on the lab-treated samples. Certain analyses are done on both untreated and lab-treated samples to enable prediction of various ion concentrations and pH of the final water.

The thorough sampling procedure of the field evaluation (which invariably yields two or four dozen quart samples of fluid from each sump), coupled with some simple analyses on the individual samples in the laboratory, has proven time and time again that sump fluids tend to become stratified. This is especially true of sump fluids containing a high concentration of suspended solids. A typical example of a stratified sump is illustrated by the data in Table 1 (page 7), in which the results of calcium, chloride and pH determinations are listed according to sample depth. The data show that all three - the calcium content, the chloride content, and the pH of the fluid - increase remarkably with increasing fluid depth, and that the ions appear to be associated with the suspended solids. Similarly, it can be shown that the level of dissolved, toxic organics in a surface sample can be radically different than that in a depth sample. This wide variation in fluid composition in a stratified sump is emphasized, because is points out the necessity of the multi-sample approach, so that a composite sample can be made up to represent the majority of the fluid body in the sump.

2. Cost Projection and Contract Bid

Based on the information of the sump evaluation(s), the total cost to treat and dispose of the sump fluids on a given lease is estimated. This cost projection can be influenced appreciably if contracts to treat other sumps in the same general area have been won, in that optimum scheduling of equipment and crew reduces the projected cost per contract.

The total treatment and disposal cost is always specified on a contract bid, although the cost expressed in cents per barrel of the

Table 1

SELECTED ANALYSES ON SAMPLES ACCORDING TO DEPTH

Sample Elevation	Sample Point	Sample Appearance	Ca ppm.	Cl ppm.	pH
surface	12	almost clear	300	1 650	7.1
3' depth	2	almost clear	320	2 330	7.4
	5	almost clear	360	2 720	7.2
	7	almost clear	360	2 820	7.5
3' average			350	2 620	7.4
6' depth	4	almost clear	480	6 800	9.2
	9	almost clear	500	7 000	9.2
6' average			490	6 900	9.2
8' depth	3	almost clear	560	7 000	9.3
10' depth	1	light solids	600	7 000	8.2
	6	high solids	5 360	11 650	9.6
	8	high solids	400	6 900	10.6
	10	light solids	680	6 600	10.9
	11	light solids	560	6 700	9.2
10' average			1 520	7 990	9.7

total fluids to be treated can be determined from the information in the sump evaluation.

3. Field Treatment and Disposal

The total sump treatment and disposal process can be broken down into five operations - oil removal, prior clarification, water detoxification, final clarification, and pump-out.

Removal of oil from a sump is necessary, not just to facilitate the subsequent toxicity reduction step, but to make it economically feasible as well. In most cases, the residual volume of oil in a sump after the oil removal step should be as low as a barrel or less. The quickest and cheapest method of oil removal is to burn it on the surface of the fluid body. If permission to do so cannot be obtained from the regulatory bodies, usually because a real fire hazard to surrounding vegetation exists, then it is necessary to skim the oil from the sump. In addition to provision of light mechanical equipment for this skimming and removal operation, a liquid surfactant is sometimes used to assist in moving the oil across the surface of the water. The oil scum removed from the sump is preferably put into a small auxiliary pit for subsequent burial there, or for ultimate spreading and mixing into the topsoil on the lease.

A prior clarification step is necessary if the concentration of suspended solids in the fluid body above the settled mud layer is considered too high, in anticipation that the suspended solids would interfere with the chemicals used in the subsequent detoxification of the water phase. Clarification of the sump water is accomplished by a flocculation step followed by a period of time sufficient to allow settling of the flocculated solids to the bottom of the sump. The flocculation step is carried out by dispersing coagulants and flocculants (polyelectrolytes) into the sump water at predetermined concentrations. A truck-mounted equipment assembly, consisting primarily of a pumping and solutioning unit, and a floating sump mixer are provided to effect this step. The truck-mounted units can recirculate the sump contents at rates up to about 3 000 barrels/hour, while the floating mixers can turn the sump contents over at rates up to about 9 000 barrels/hour. Depending on the original solids concentration in the sump and the "tightness" of the solids sludge after settling, usually about 60% of the total fluid body is obtained as a solids-free water layer.

If a sump has been classified as toxic, in that an untreated sample of it has failed the trout bioassay, then it must be treated to reduce the level of toxic components dissolved in the water. This is done by thoroughly mixing treatment chemicals into the body of fluid using the truck-mounted unit in conjunction with a floating sump mixer. In addition to removal of dissolved, toxic components from the water, it is sometimes necessary to adjust the pH of the water so that ultimately it will pass a trout check. Choice of the kind of acid for pH adjustment is important, so that the concentration limit on the anion added (chloride, sulphate or phosphate) is not exceeded.

A final clarification step is always required after the detoxification step in order to remove any residual suspended solids and thus produce the clarify required for off-lease disposal of the treated water. As described above, clarification is accomplished by coagulation-flocculation and sedimentation of the solids.

After the detoxification and clarification steps have been completed, a representative sample of the final water to be pumped out is taken for a final trout bioassay and water analysis. These test are done at a certified commercial laboratory or at the Alberta Energy Resources Conservation Board laboratory, but in any event, the results of the tests are made available to the pertinent regulatory body personnel. Because a successful trout check requires four days, there is usually a time lapse of at least a week between the final clarification step and the pump-out step.

Pump-out of the clarified, treated water from a sump is done only after permission is obtained from the regulatory bodies and very often is done under their surveillance. Because it is invariably desired to pump the water on the land adjacent to the lease, the applicable regulatory body and/or land owner is approached ahead of time so that the exact area for disposal is agreed to by all parties. Two methods of pump-out have been offered - one using open-gated irrigation hose and the second using an irrigation gun (sprinkler). The open-gated irrigation hose is the preferred pump-out method because of its higher disposal rate (about 3 000 barrels/hour) for the horsepower provided, and in two years of commercial operation it has always been used for the pump-out step.

There are certain practical considerations that place limitations or constraints on the use of the process. Because the sump contents must be in the fluid state to undergo the various operations, the process is a seasonal one, in that use of it is generally limited to the time between spring thaw and fall freeze-up. Accessibility, both to the lease and to the sump, is essential for each processing step. Usually these steps are spaced across a time span of more than two weeks, with several trips to the lease involved. The service rig must be able to park within about 15 feet of the sump, and vehicular mobility on the lease is required to some extent for all the processing steps.

The primary feature of the treatment process is its ability to reduce the level of dissolved, toxic components and suspended solids in the sump water so that the trout check can be passed. The process does not lower the chloride content of the water. Therefore, if the initial chloride concentration of the untreated water already exceeds the limit set by the regulatory bodies for disposal in a given area, then disposal of the treated water, even if the trout check is passed, may still be a problem.

COST OF THE PROCESS

Selected statistics and cost data on all the sumps treated and disposed of by Wilson Mud Service Ltd. in 1973 and 1974 are presented in Table 2 (on the following page). From this data, it appears that the overall average cost of the process is in the order of 30¢/barrel of sump fluids treated. However, as Table 2 also shows, the cost varied widely - from below 20¢ to above 60¢/barrel of fluids treated.

This treatment cost variation can be traced to various contributory factors, such as sump size, the number of sumps per lease, the remote locations involved, and especially the nature and varied composition of the fluids themselves. The effect of some of these factors on treatment cost can be shown by segregating the treatment contracts of 1974 into two categories, one in which no special problems were apparent and the treatments were considered "typical", and the

Table 2

SELECTED STATISTICS AND COST DATA ON TREATED SUMPS

	1973	1974
Number of treatment disposal contracts	15	22
Total fluids volume per lease (barrels)		
- average	33 200	34 000
- range	3 000-74 000	12 000-75 000
Volume pumped out (% of total treated)	62.5	51.9
Depth of well drilled (feet)		
- average	12 260	11 550
- range	6 400-18 000	7 280-18 530
Total fluids volume (barrels) per foot of hole drilled	3.02	2.95
Total treatment and disposal cost ($) per contract		
- average	9 220	10 420
- range	1 500-20 000	1 500-34 000
Total weighted cost (¢/barrel) of treated fluid		
- average	27.8	30.6
- range	17.1-57.8	13.5-61.5

other in which two factors (the nature of the fluids, and very remote locations) obviously increased the cost and the treatments were considered "non-typical". This has been done to derive the statistics and cost data displayed in Table 3 (on page 13), where the "non-typical" contracts of 1974 include four sumps containing invert drilling fluid systems, one sump containing a modified lignite drilling fluid system, and two sumps remotely located in British Columbia. The data of Table 3 shows that the average treatment cost (about 44¢/barrel of fluid treated) of these seven special problem sumps is almost double that (at about 23¢/barrel of fluid treated) of the other fifteen contracts. The higher treatment cost of these special problem sumps was despite their larger sump size, which normally tends to decrease the cost expressed in cents per barrel of fluid treated.

Based on the cost projections arising from about 120 sump evaluations done to date, and on the actual costs of 42 contracts completed successfully in the field, in can be concluded that the one factor that has the greatest influence on a sump treatment program, and therefore the treatment cost, is the nature of the drilling fluid system used to drill the well. In general, the cost projected to treat sumps derived from either an invert or a KCl-polymer drilling fluid system is in the order of 35-40¢/barrel of fluid treated, whereas the cost projected to treat sumps derived from various freshwater-gel systems is about 30% less. These particular drilling fluid systems are mentioned, because they are the ones that generally have been encountered in the sumps evaluated to date.

Table 3

SELECTED STATISTICS AND COST DATA ON TREATED SUMPS

SEGREGATION OF 1974 CONTRACTS

	1974 Treatment Contracts	
	Typical	Non-typical
Number of treatment disposal contracts	15	7
Total fluids volume per lease (barrels)		
- average	31 200	40 100
- range	12 000-75 000	19 000-66 000
Volume pumped out (% of total treated)	48.1	58.4
Depth of well drilled (feet)		
- average	10 520	13 740
- range	7 280-16 910	8 900-18 530
Total fluids volume (barrels) per foot of hole drilled	2.97	2.92
Total treatment and disposal cost ($) per contract		
- average	7 090	17 540
- range	1 500-13 300	6 400-34 000
Total weighted cost (¢/barrel) of treated fluid		
- average	22.7	43.7
- range	13.5-33.6	32.3-61.5

DRILLING FLUID DEWATERING

R. Clark, D.R. Card[1]

INTRODUCTION

NEYRFOR CANADA is a service company concerned with the dewatering of drilling fluid. Our drilling experience and a simple, reliable process enable us to operate in any remote location.

The objectives of the techniques are to:

- reduce the volume of mud pits;
- put the lease into restored condition as soon as possible;
- reduce time and cost of lease construction;.

NEYRFOR is one of a group of companies under ALSTHOM-ATLANTIQUE. The 17 world offices of NEYRFOR have over 35 years experience in the drilling industry. Technical advice, engineering and manufacturing is supplied by the NEYRTEC division whose design capabilities include turbines, hydroelectric dams and nuclear power plants. The Company's 50 000 employees are available to assist in solving difficult problems.

Several years ago, the Company was approached by oil companies to look at the problem of drilling fluid disposal. Conventional methods often left behind problems that dragged on, costing the oil companies time, money and bad publicity. In co-operation with the clients, the Tassfor Dewatering System was developed for the oil industry.

The resulting system, known as a Tassfor, dewaters drilling fluid producing water and sludge. The water is available for reuse or disposal. Mechanical equipment can be used to move the sludge on lease or remove it for landfill.

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[1] NEYRFOR CANADA Limited, Calgary, Alberta.

Conventional sump treatment processes the naturally separated water forming the upper layer. Often, this removes less than 50% of the volume. What is left is the suspended mud. Disposing of the mud now involves digging enough small pits or trenches to be able to cap portions of the fluid.

The chemistry developed by the mud man is designed to keep the particles in suspension. A method to destabilize the drilling fluid is required. By introducing a cation exchange, the stabilization of the fluid is upset and coagulation occurs. To further aid in taking apart the drilling fluid, a polyelectrolyte polymer is added. Pinpoint flocs form an agglomeration that is large and easily handled. From here, mechanical means are used to squeeze the water from the flocs.

The chemical preparation of drilling fluid for any dewatering equipment is understood and widely known. The process involves no "Black Magic" but uses chemicals and machinery easily available. Based on the chemical process, different mechanical means can be used to extract water. The end results of each method are similar.

The Tassfor is a complete unit designed to apply chemical treatment followed by mechanical compaction to waste drilling fluid. The dryness is equal to or superior to that obtained with other processes, without using high pressures.

THE UNIT

The Tassfor we have now is a unit brought from France to demonstrate and study the feasibility of the process for Alberta.

As a result, we are now manufacturing, in Alberta, a new unit. With a capacity of 20 to 25 m^3, essentially two to three tonnes of dry solids per hour, this is double the output of the current unit.

Both Tassfors are self-powered and mounted on trailers.

THE PROCESS

The main mud pit, dug during lease construction, receives the waste mud and water. A floating agitator (stirring system) is installed in the sump. When used, the agitator keeps particles in suspension providing an homogeneous feed.

A submersible pump transfers the fluid to a cyclone where solids over 80 microns are rejected. Removing these particles protects pumps and processing equipment. Mud is stored in a 10 m^3 buffer tank that allows the feed to be of a consistent quality. The mud is extracted by a volumetric pump allowing controllable flow to the rest of the equipment.

The mud to be treated is delivered through a mixer. In this section, a regulated dose of flocculants is added to destabilize the fluid and start flocculation. The fluid is then delivered to the Tassfor tank where flocculation continues.

The polyelectrolyte polymer used for flocculation is in a powder or liquid form. An automatic flocculation station prepares the feed solution of a desired concentration. The operation is continuous allowing the Tassfor to run non-stop. It is only necessary to have the powder available to have a uniform polymer solution continuously prepared.

The mixture now appears different than the initial liquid as the flocs have formed. The mixture is introduced to the fluid bed. As the arriving flocs can be light and perhaps weak, they now meet with the heavier and larger flocs of the bed. The bed forms a moving and regenerating filter, efficiently trapping the fine flocs that cross it. The bed permits the rapid passage of clarified water. At the interface, the speed of the water is near 100 m/hr.

The clarified water rises in the tank and decants into the overflow.

The large heavy flocs descend into the conical section. En route to and in the conical section, the flocs receive continual agitation releasing more water. The mud continues to the compactor screw.

The lower part of the unit is an Archimedes screw surrounded by a grill that carries the mud to the exit. Compacting and drying of the mud continues as it moves across the grill. A regulated valve at the outlet opposes the pressure in the unit allowing control of the throughput and dryness.

Statistics for Test Unit

Input		90 - 130 g/L dry solids
		10 - 12 m^3/hr drilling fluid
Output	Solids	40 - 60% by weight
		Flow 1 T/hr dry solids
		2.0 - 1.5 m^3/hr
	Liquid	Solids less than 50 mg/L
		Flow 9 - 10 m^3/hr
		pH 5.5 - 8.0

The efficiency of solids capture is typically over 99% and depends on the type of dry material in the mud feed.

Obviously, throughput is also related to the concentration of solids in the water to be treated.

The toxicity of the polymer is indicated by 96 hour trout check where up to 2 000-5 000 ppm of polymer has been used.

WATER OUTPUT

The water produced from the Tassfor process is most likely ready for disposal under the guidelines of the Energy Resources Conservation Board ID-OG 75-2. The suspended particles are removed in the Tassfor and the pH of the sludge and water output has been adjusted. Should the fluid not meet specifications, a conventional water treatment will be applied. However in a sample of 17 locations, only one has failed to meet requirements. After investigation, a high H_2S content was found in the water of the one location.

Thus it can be said that the process, used to destabilize and remove suspended solids, generally yields water of a quality suitable for immediate disposal.

STORAGE OF THE COMPACTED MUD

Dryness has been enhanced by the Tassfor giving a product that is at least a paste and normally in a pelletable form. Its flow characteristic is similar to lava and rests at an angle of 10-15%.

As the mud spreads, it remains fairly static and because of its natural hydrophobic character, clear water is rapidly released. It has been recorded that mud of 60% dryness goes to 75% in 24 hours. The mud drains, cracks, and dries rapidly with time. The solids, tied up with the polymer, are resistant to taking on more water from a source such as rain.

The heavy sludge, after some drying, can be mechanically moved. The use of front-end loaders, backhoes and trucks is common.

Thus the compaction and treatment of mud delivers a product that can be mechanically handled or stored as is. Under storage, the mud is stable and occupies 60% less volume. The equipment to achieve this is simple, rugged and requires little maintenance. In fact in three years of oilfield application, no spare parts for the Tassfor itself have been used.

BIODEGRADABLE

The polymer used to consolidate the solids can eventually be removed. Prolonged flushing with water will dilute the polymer remaining with the solids. However, without agitation there is no reason for the solids to go back to solution.

Being organic, the polymer can also be biodegraded. With time and good conditions for activity, it will eventually be consumed. As the sludge contains bentonite, a carbon-nitrogen based polymer and a good source of calcium, it is not anticipated that there will be any problem in re-establishing vegetation after spreading sludge on the surface.

CHEMICALS

In the operation of the Tassfor, the chemicals used are normally gypsum and polymer flocculant. Gypsum is one product that coagulates the particles in bentonite drilling fluid. When incorporating drilling fluid into the soil, the presence of gypsum can be considered beneficial. For saline soils, the use of gypsum or other calcium sources is of particular import.

To complete the process of bringing the particles together, normally a polyelectrolyte flocculant is sufficient. The polymer forms large flocs that can then be mechanically dewatered to form the output sludge. The dosage is continually monitored to ensure satisfactory flocculation but not excess usage. The pH of the discharge water has been adjusted, bringing it intop a range of 5.5-8.5, suitable for disposal.

Flocculant of the type used is considered non-hazardous. On the fish bioassay, concentrations between 2 000-5 000 ppm have shown non-toxic results.

The physical hazard to the operator may occur as dust from the powder or a slip hazard from the feed solution. In general, the chemicals used pose little personal or environmental hazard.

SALT

The dewatering equipment does not remove salts from solution. As a mechanical device, there is only a separation of the liquid and solids phase.

Water separated from the mud contains as much salt as was dissolved in the solution before the separation. Where a salt saturated mud exists, yes, the saturated water is separated from the solids. Fresh water can then be mixed with the solids allowing the water to dissolve more salt, up to the soluability allowed by the physical conditions.

Repeated squeezing and dewatering of the mud followed by a mixing with freshwater, will succeed in reducing the salt in the mud that is available to go into the solution. The Tassfor can be used in the compaction, dewatering of the mud.

Often, the object of the washing is to reduce the amount of sodium or potassium available in the mud. The result is a better relationship between the quantities of Na, Ca and Mg in the soil. The relationship can be altered by adding a source of calcium such as gypsum or calcium nitrate.

The sodium based products found in drilling fluid are designed to aid in the dispersion and suspension of the particles in the fluid. Down the hole, the dispersion helps in forming a filter cake with the desirable quality of being water tight.

When mixed with soil, the dispersion caused by the drilling fluid allows the soil to be washed away in suspension. On drying, the fine suspension forms a filter cake (water tight) on the surface that dries to become hardpan. This process removes topsoil and makes new germination difficult.

The presence of calcium negates the characteristics of the drilling fluid, overcoming the dispersion tendency and the resulting hardpan.

TREATMENT COSTS

The cost of treating a sump depends on what is in the sump. Obviously one can anticipate a high cost for a sump that is high in suspended solids and toxic.

During a year, the average cost to treat the water layer should be approximately $1.25/barrel removed from the lease. The cost includes initial site sampling, lab report, treatment program, treatment and finally water disposal. As some sumps are non-toxic, all of these items will not be required and thus the cost per barrel will be low.

Below the water layer is a layer of suspended solids. To start to process the solids in the water requires more time and more chemicals than for the same volume of water. As effort is cost related, it is more expensive to treat the solids layer with typical costs being $2.00-$2.50/barrel. A wide price range exists because of the quantity of solids, tonnes of dry solids per cubic metre, to be removed. The quality of the material contained in the water affects the work necessary to detoxify the water produced after dewatering.

Being able to dewater drilling fluid allows one to literally get to the bottom of the problem and empty a sump. Mechanically, the volume to be handled is smaller and easier. Whether buried or worked into the surface, the disposal is more secure.

FRANCE

In France, there are similar regulatory bodies. The discharge guidelines for fluid are:

pH	6-8
TSS	50 mg/L
COD	300 mg/L
BOD	100 mg/L
Cl	30 kg/day

For each lease, the used drilling fluid must be treated and the sump area restored. To empty the sump and leave it in a stable condition, the fluid is dewatered. Burying the sludge makes for a stable landfill and requires less area than disposing of the fluid itself. In some cases, the dewatered sludge is trucked to a landfill. The smaller volume of the sludge as opposed to the drilling fluid reduces transportation costs.

In the case of poor soil conditions, a liner is immediately used to contain water or drilling fluid. If the pit contains water, the liner is recovered. If the pit contained drilling fluid, as much fluid as possible is removed from the pit and dewatered. The liner, that cannot be recovered from the emptied pit, is buried. Cement may be added on some locations to stabilize the sludge being buried.

ADVANTAGES

- Meet current environmental regulations;
- Stable lease ready for production;
- Small pits, reduces volume to be stored allowing smaller pits;
- Environmentally sensitive areas: muskeg, hills, agricultural;
- Reduces construction and cleanup;
- Know cleanup will be complete.

APPLICATION

The Tassfor dewatering system separates the solid and liquid portion of a drilling fluid. The solids can be removed. The function can be viewed as either removing the solids or removing the water. For disposal, one would like the water removed leaving stable solids. For drilling, one would like the solids removed leaving water to be used for example in low solids mud drilling.

In drilling fluid disposal, the object is to reduce the volume of material requiring disposal by removing as much water as possible. Where a sump is high in suspended solids, i.e. sump has not settled, a great deal of effort is required to contain the viscous fluid. The sludge created from dewatering is physically easier to contain.

OTHER POTENTIAL SITUATION

* Multi-hole programs where one secure sump location can be selected;
* Poor soil condition. The size of pits and the volume of waste fluid on site at any given time can be kept to a minimum;
* Sumps where additional land is required for disposal;
* Large sumps where the disposal land is available but you do not wish to tear it up;
* Where trenching may be a concern;
* Want empty pits before switching to an invert mud system;
* Critical environmental areas - swamp or hills. Company desires to be in and out with minimum impact;
* Obtain a 40-60% dry sludge from the drilling fluid;
* Simplify the restoration of a lease back to a stable platform.

A solution that is economically acceptable requires collaboration between the regulatory bodies, oil company, drilling contractor and the service company.

DISPOSAL
OF
DRILLING FLUID

R. Clark[1]

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[1] NEYRFOR CANADA Limited, Calgary, Alberta.

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SUMMARY

When assessing a drilling fluid for disposal, the drilling fluid as a whole should be considered. Aside from the unappealing appearance of drilling mud, the hazards associated with the separate components making up the fluid and the hazards associated with the composite whole fluid are completely different.

The drilling industry must co-operate with regulatory agencies and assist them to develop mutual solutions to disposal problems. Increased regulation without industry input will result in more costly drilling. Industry should set its own standards before being required to by regulation.

Drilling fluid is probably handled better than any other hazardous waste. In Alberta, during 1982, the industry generated over 2 500 000 m^3 (15.5 million barrels) of fluid. The disposal of this fluid has generated very few problems. There are a variety of acceptable disposal methods each applicable to certain situations.

By being aware of what we are doing and why, we will be able to dispose of our drilling fluids without damaging the environment.

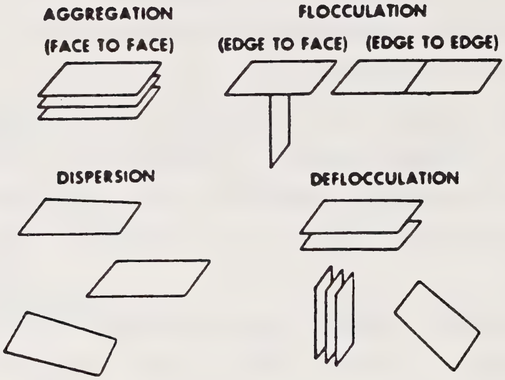
DRILLING FLUIDS

Mud, or Drilling Fluid, is a three letter word that seems simple but can dazzle a person with its complexity. The properties of viscosity and density are controlled by adding various chemicals. The toxicity of these chemicals is questioned when the drilling fluid is to be disposed of.

The water based mud system is the most common and thus presents the largest disposal problem. Bentonite is widely used in water based fluids to increase viscosity and to control water loss. Bentonite hydrates or absorbs water readily, causing swelling and particle separation.

It is how these clay particles link together and associate with each other that help determine the fluids viscosity. Due to different chemical reactions, clay particles will link together in four ways.

Aggregation, face-to-face linking, leads to thicken plates. This decreases the number of particles and causes a decrease in the viscosity. Aggregation can be caused by the introduction of divalent cations, such as Ca++, to the drilling fluid. After an initial increase, the viscosity will decrease to a value lower than it was initially.



Dispersion is the reverse of aggregation. The particles absorb water and hydrate or disperse. Dispersion leads to a greater number of particles, increased surface area, and higher viscosity. The degree of dispersion depends on the electrolyte content of the water, temperature, time, exchangeable cations and the clay concentration.

Flocculation is the edge on edge-to-face association leading to the formation of a house of cards structure. This causes an increase in viscosity.

Deflocculation occurs when materials added to the mud neutralize charges with the result that particles no longer associate edge-to-edge or edge-to-face. These chemicals are called thinners (lignosulphonates, lignites and phosphates). In order to maintain viscosity in the proper and desired range, the concentration of solids and chemical additives must be controlled.

In water based muds, the pH is raised from a neutral 7 for water to about 9.5 where the mud becomes basic. It is desirable to have the pH in the higher range to control viscosity, reduce corrosion on the drilling string and stabilize shales. The pH is usually raised by adding caustic - NaOH.

Another function of a drilling mud is to deposit a filter cake on the well bore. The cake reduces the permeability at the well bore and minimizes the fluid loss into a formation. Caving is also prevented by consolidating sands and gravels.

The building of a filter cake is disrupted by contaminants that flocculate the bentonite. Sodium carboxymethylcellulose (CMC) will plug the holes caused by poor stacking or sodium lignosulphonate will neutralize the charges and redisperse the flocculated bentonite.

Some shale formations hydrate when in contact with a water based drilling fluid. The shale sloughs, producing large over gauge sections in the well bore requiring increased mud viscosity to clean the hole. To maintain gauge hole, an inhibitor, such as potassium chloride is added to the mud to reduce the hydration of the shale and prevent caving problems.

A chemical thinner is used to reduce the attractive forces between the solids in the mud, when increasing viscosity becomes a problem. Common thinners are phosphates, polyphosphates, plant tannins, lignites, and lignosulphonate wood biproducts.

An increase in mud density reduces penetration rate and can result in problems such as stuck pipe. To reduce the mud density the mud system is diluted by dumping some of the mud and replacing it with water. Discarded fluid is safely contained in large pits or sumps until it can be disposed of.

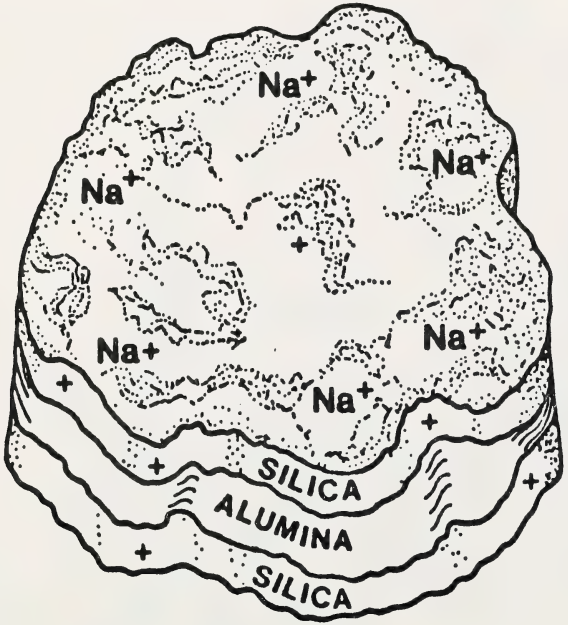
To calculate the required sump capacity, we can estimate that a rig will generate about 0.5 m^3 of fluid per metre drilled. For a 2 000 metre well, we anticipate 1 000 m^3 of fluid as a target volume for disposal.

One common problem is that rig crews erroneously view the sump as a garbage pit. Other wastes are added to the sump that will make a non-toxic and create a more difficult disposal. Some of the items ending up in a sump are:

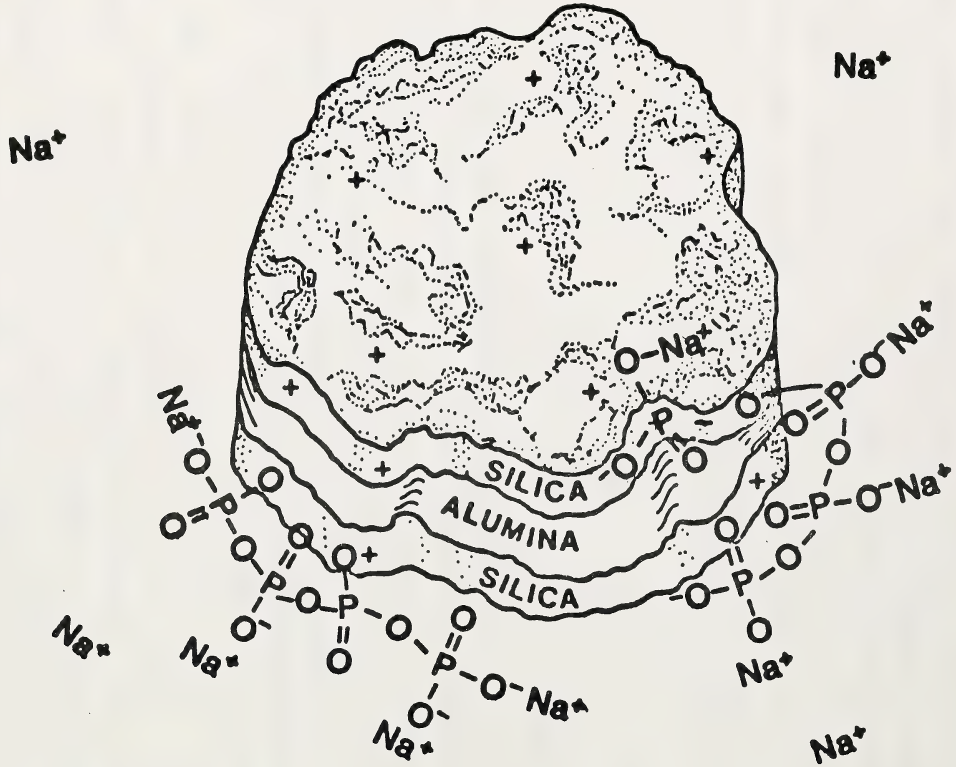
- scrap iron, drums, cans
- mud sacks
- casing protectors
- engine oil
- rig detergent

Each of these items can be readily disposed of if they are not mixed together, but isolated in separate containers or areas.

SODIUM MONTMORILLONITE



ACTION OF SODIUM TETRAPHOSPHATE ON A TYPICAL BENTONITE PARTICLE



REGULATIONS

Hazardous wastes can be defined as those substances that may enter the environment in a quantity or concentration or under the conditions that may constitute a danger to the environment, the plant or animal life or to human health.

The disposal of drilling fluid in Alberta is regulated by the Energy Resources Conservation Board. Interim Directive ID-OG 75-2 describes the guidelines to be followed when conducting disposal. A role of the ERCB is to assure that industry complies with these requirements. The following legislation is applicable to hazardous wastes: the federal Bill 18 - Transportation of Dangerous Goods, Alberta Bill 16 - Hazardous Chemical Act, and Alberta Bill 8 - Transportation of Dangerous Goods.

The Alberta guidelines specify that if the volume of fluid is less than 6 000 bbls (950 m^3) it can be disposed on-lease. Approval may be given by the ERCB to dispose of more than 6 000 bbls of fluid to the lease providing it can be shown that the entire contents of the sump will be confined to the site. For off-lease disposal, the fluid must meet certain criteria which will demonstrate that the fluid is minimally toxic.

WHAT IS TOXIC

What are the hazardous components in drilling fluid? Oil, salts, and soluable trace elements of zinc, lead copper, nickel, chromium, mercury, arsenic and barium are commonly considered hazardous. The hazards of the components which makeup of a fluid may be great; the hazards of the mixed components which constitute the complete fluid are almost uniformly small.

When drilling fluid is applied on plants, the Canadian Petroleum Association study indicated that the detrimental effects were from soluable salts, exchangable sodium and diesel oil. The detrimental effects decline with time and the plant growth shows positive recovery after three years.

Drilling fluid is treated with many additives to control its properties. Some are listed in the following table; many have common application in the food industry. Therefore, arriving at a decision as to what is hazardous can be difficult.

In the case of zinc, there are recommended required dietary limits in contrast to levels that may be toxic. The fact that a metal is present, does not mean that it is available for plant uptake. Ions like that of arsenic form complexes that are very stable. It is highly unlikely that a metal is soluable or reactive. Furthermore, bentonite is used commercially as a filtration media to remove metal ions. The presence of a reactive heavy metal ion is highly unlikely in drilling fluids. Generally the hazardous elements exist at a lower level in drilling fluid than in background levels of the environment.

DISPOSAL METHODS

Left with a sump full of fluid, the immediate problem is what to do with it? Eight alternate methods are described below and the use of each depends on the particular situation. Each sump should be evaluated individually.

Trapping - means the containment of the drilling fluid in an impermeable clay pit so that the fluid cannot migrate after the pit is sealed in. This is the most economical method when the fluid can be contained on-lease. Adverse consequences with this method are that the fluid is not likely to break down, that anaerobic decay is possible and that the pit may settle requiring secondary cleanup. Finally, there is the risk that the fluid will eventually leak into the surrounding soil or water table.

Trenching - involves the use of a backhoe to dig deep slots in the surface of the lease. As the trenches are narrow, they can easily be bridged over and capped. A large volume of fluid can be contained this way. The adverse consequences are similar to those for trapping. In addition, this method has greater expense and a larger amount of the lease must be disturbed.

Squeezing - is conducted by adding fill from one end of the sump. Some mixing takes place but excess fluid will flow from the sump to be

ADDITIVES

DRILLING	FOOD
SAPP	COOKIES, PASTRY
BICARB OF SODA	MOST
ALUMINIUM SILICATE	COFFEE WHITENER
CMC	COOKIES, CAKE
GUAR GUM	ICE CREAM
$CaSO_4$	DONUTS
STARCH	THICKENER

contained in a second pit that has been prepared. The fluid in the second pit is squeezed into a third pit. In each successive operation, more fluid is mixed with the fill material until all the fluid is disposed of. While a little more costly, secondary restoration is usually not required and the fluid will dewater.

Bullet - using a bullet shaped object behind the ripper of a bulldozer, the ground can be fractured and round channels can be made. The lighter fluid flows into these channels and can be absorbed into the broken ground. After squeezing the sludge, the roughened surface will accept some of the sludge. Evaporation will dewater the sludge.

Field trials indicate that there is little extra cost. The near surface disposal allows breakdown of the fluid with the benefit of no secondary cleanup. The technique may allow more than 6 000 bbls to be disposed of on lease.

Chemical Treatment - is one of the most common steps taken as part of the disposal process. The purpose is to reduce the toxicity of the fluid portion so that it can be removed. By this process, any contaminants are tied up in a sludge that because of its smaller volume can be contained on the lease.

The most obvious contaminant will be oil on the surface of the sump. The oil can be skimmed off or burned. Dissolved organics are removed by adding charcoal, talc or bentonite. The pH is adjusted with acid or lime as needs dictate. The presence of salts is sometimes adjusted by adding chemicals that will tie up or balance the salt concentrations, leaving a more acceptable fluid. The final step is to clarify the fluid using polymers to aid flocculation. The clarity and quantity of water recovered depends on the effectiveness of the flocculating polymer selected.

The treated fluid is acceptable for off-lease disposal and is normally pumped onto the surrounding ground. The techniques available for spreading the water include the use of an open ended pipe, perforated hose or an irrigation type sprayer. Erosion problems and the level of chloride loading on the soil must be considered for each method. The choice will probably be determined by the agency giving approval for the method of disposal.

The use of bacteria to treat a toxic sump is another approach. Micro-organisms use chloride during growth and coagulate solids. The process involves low labour cost and is self sustaining. Any oily waste will probably be used as a bacterial food source and thus be removed. The drawback to this process is that months of aging is required and the process is hindered by cold temperatures.

Downhole Disposal - If you have a well that has at least 600 m of casing, you may be able to dispose of fluid to a subsurface zone. You must show that the disposal zone is isolated so that the waste fluid cannot contaminate other formations. It is rare to have a well with intermediate or surface casing set to a sufficient depth. The cost to extend the casing in anticipation of using this method is usually prohibitive.

In the case of remote disposal, you are then faced with the cost of trucking. Where an existing disposal well is located near several new wells, then downhole disposal may economically be feasible.

Spreading Directly on the Land - Water based fluids may be spread directly on the land, agricultural or forested areas, if consideration is given to the makeup of the fluid. The mud should have a pH compatible with the soil and the chloride, sodium and oil content should be minimal. Fluid spread on the surface has excellent exposure to the air, bacteria and sunshine to aid its degradation. In sandy soils, the presence of clay will increase the soil's ability to retain moisture. In Alberta, the spreading of mud would have to be approved through direct application to the appropriate regulatory body, ERCB or Alberta Environment. In Saskatchewan, subject to approval by the Department of Energy and Mines, an average of 75 bbls/acre may be spread; therefore, it is possible to dispose of 12 000 bbl on a quarter section.

When using this method, the oil company is liable should any damage occur. Therefore, soil samples should be taken before spreading to determine if the mud will have any adverse effects. In particular, the sodium and chloride concentrations should be considered.

Incineration - is a method applicable to the disposal of oil based muds that can not be reclaimed or spread on roads. For water based muds, the capital cost and energy costs would usually be prohibitive. If the product is to be incinerated, it should be concentrated, making incineration economically more feasible.

CHLORIDE

Tests conducted by the Canadian Petroleum Association (1980) show that chlorides have an immediate toxic effect on plant life. It is believed that the damage to plants is caused by the desiccation of cells in contact with the salt and the uptake of salt in the plants. After a three year period, recovery appears to be 80%.

The measurement of chloride, a simple field test, is one of the first measurements taken. The value obtained is used to assess the hazard posed by the chlorides themselves but is often also used to relate the presence of sodium. In the case of salt water, this correspondence may be quite close. However, in drilling fluid the relationship can be out by several times the measured chloride value. The table below shows some field examples of Na and Cl concentrations. The wide range between the two would raise a question as to the use of chloride concentration to indicate the presence of sodium.

CONCENTRATION COMPARISON

	Na^+ppm	Cl^-ppm
A	671	1 625
B	240	725
C	1 250	55
D	709	41
E	675	217
Soil	80	116
Soil	10	15

SODIUM

As seen in the above table, estimating the amount of sodium present, using the value of chlorides as a guide, can be misleading. The sodium concentration should be measured directly, as should calcium and magnesium, so that the sodium adsorption ration (SAR) can be determined.

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}}$$

Where concentrations are measured in meq/litre of saturated extract.

Fluid with values above 10 have the potential to cause damage to the soil.

When fluid is spread on productive soil, the same dispersion and filter caking properties found in the drilling mud can produce erosion and hard pan in the soil. The sodium is generally regarded as the bad element in soils because of its possible detrimental effects.

There are many sources of sodium including bentonite which is a sodium clay. Many of the additives for dispersion are sodium based - see table. In KCl muds, the K+ ion exchanges with the Na+ ion in the shale resulting in a greater sodium ion concentration in the mud. The sodium concentration should be measured to assess its effects.

SODIUM

Caustic	NaOH
Soda Ash	Na_2CO_3
Bicarb	$NaHCO_3$
Sodium Acid Pyrophosphate	SAPP
Sodium Carboxymethyl Cellulose	CMC
Sodium Aluminium Silicate	Bentonite

CALCIUM

When we are concerned about the high concentration of sodium ions and the bad effect on the soils, then it is possible to dominate the sodium salts with the addition of a calcium salt. The calcium replaces the sodium in the exchange complex leaving a calcium saturated soil.

Calcium can be used to reduce the adverse effects of sodium on soils.

The calcium can be supplied in several forms:

- Calcium Chloride - soluable but has a chloride ion
- Calcium Carbonate - soluable but only effective on acid soils
- Calcium Sulphate (gypsum) - less soluable, low cost (14¢/kg - Calgary)
- Calcium Nitrate - soluable, moderate price (53¢/kg - Calgary), also a fertilizer

The use of gypsum or calcium nitrate is preferred. Gypsum has been applied, in reclamation activity, at seven tonnes per hectare (three tones per acre). Calcium nitrate has been used at 100 kg/ha (90 lbs./acre). Calcium addition can be used in conjunction with the disposal methods of spreading, the bullet, squeezing or as part of a chemical treatment. Each case must be considered separately.

SOLIDS CONTROL EQUIPMENT

Typical solids control equipment systems include a various combination of shale shakers, desander, desilter, mud cleaner and centrifuge.

The proper application of solids equipment is to use it continuously throughout a drilling program. If the equipment is not used correctly or maintained, solids removal will be inefficient and the density of drilling fluid will increase. To reduce the density and associated rheological problems, the rig dumps a portion of the fluid in the sump and dilutes the remaining fluid. The density control problem can be dramatic and the subsequent dumping can double the sump volume.

Some daily rental rates for solid control equipment can add $200 to $800/day to the rig cost. Increased penetration rate, reduced mud costs and longer equipment life are some benefits. Cleanup costs are lower as the minimized volume helps in the disposal.

A passive method of solids removal is the use of the sump itself. With some preplanning of the sump design, solids can be encouraged to settle out. A light fluid is then available at the return end of the sump for use as makeup fluid. A design that has shown promise from initial field trials is a circulating G sump. However, due to freezing conditions in the winter season, any recirculation is difficult.

GENERAL RECOMMENDATIONS

In order to reduce the toxicity, to dispose of drilling fluid and to clean up the lease, the following should be observed:

- Planning for the disposal of sump fluids should be a part of the drilling preplanning and the amount of sump fluid should be monitored during drilling to prevent problems of poor fluid management.
- Only identifiable chemicals or native solids should be used.
- Chemicals considered hazardous should be used sparingly. For example, the use of KCl may be limited to part of a hole and then kept in a separate sump for disposal.
- The operating companies should preferentially use mud systems that are less toxic, if possible avoiding KCl and salt systems.
- Water can be made available for reuse in the mud systems by using a sump designed to encourage settling and by using slide pumps.
- To reduce the volume of water used to wash the rig, high pressure guns should be used. Non-toxic and biodegradable detergents should be used, if needed at all. Rig wash should be isolated.
- Engine oil, hydraulic fluid, fuels and other waste should be placed in a separate pit. The production department must be made aware of the problems that completion fluids can cause in a non-toxic sump. They too must provide separate disposal pits.
- Any metal objects, cables, barrels, thread protectors should be recovered as scrap or taken to a nuisance area.

CHEMICALLY ENHANCED CENTRIFUGING FOR REDUCING QUANTITY AND COST OF GEL- AND SALINE-BASED DRILLING WASTES

R.F. Becker[1]

SUMMARY

It is shown that by employing a chemically enhanced centrifuge (CEC) treatment for drilling fluids, the volume of fluid needed can be dramatically reduced. Additional cost savings arise from reduced haulage costs and the reuse of fluid for multiple production holes, while the environmental impact of fluid systems and fluid waste disposal are brought to a minimum.

INTRODUCTION

Drilling through rock requires a fluid to perform the following functions:

1. lubricate the bit
2. cool the bit
3. carry away cuttings
4. stabilize the walls of the hole
5. minimize fluid loss into formation
6. hold the cuttings in suspension when the fluid is not in motion.

The cost of making, handling, processing and disposing of drilling fluids (or muds, as they are sometimes known) can range from $10,000 to more than $1,000,000 per hole, depending on the size and depth of hole and types of formation encountered. Cuttings are removed mechanically from fluids so they can be reused as much as possible, but mechanical systems only remove the larger cuttings; ultrafines (particles less than 20 microns in diameter) remain. These are recirculated, accumulate and are ground still finer. Consequently, the quality of the drilling fluid deteriorates until a portion of the fluid has to be disposed of and new fluid is used as a diluent to the contaminated mud in the system. In addition, the mechanical solids removal systems require large volumes of drilling fluid to operate properly, and so a considerable amount of fluid is wasted.

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[1] Hitec Research and Development Inc., Calgary, Alberta.

BACKGROUND

In the fall of 1984, during a sump cleanup for a major Canadian oil company, Hitec began to consider the possibilities of tackling the cleanup problem at its source, the drilling fluid system. It was surmised that the Hitec equipment and chemistry could be modified to provide greater benefits in this regard. The aim was to make the equipment more mobile and use a new proprietary chemistry that would allow for the processing of fluid during the drilling operation, returning the fluid to the mud system with original qualities intact. If this could be accomplished, then the sump could be eliminated, and the volume of waste at the end of the job would be considerably reduced. It further followed that if the waste could be reduced, the cost of the drilling fluid, its handling and disposal should also be reduced.

To this end, in October of 1984 Hitec completed its first 'Active Closed Circuit' unit, which was immediately put to work in southwest Oregon for a major U.S. oil company. This application proved completely successful. The unit has since been adopted by a major U.S. resource company in a potash mining operation in Michigan using oil drilling rigs. In January of 1985 a major Canadian oil company tested the unit on two holes in a drilling operation near Inuvik, N.W.T. The purpose of this arctic operation was to evaluate the unit for later drill ship applications. Later in the same winter, units were used on four disposal wells in the Cold Lake area where the drilling fluid was salt saturated. In every case, the system has performed satisfactorily.

REUSE OF DRILLING FLUIDS TO FURTHER REDUCE THE MAGNITUDE OF DISPOSAL PROBLEMS

Because of the excellent rheological properties of the drilling fluid after it has been processed in this manner, it was felt that at the end of the hole these processed drilling fluids could be reused. Enquiries were made, therefore, of major oil companies using brine drilling fluids in the overthrust area of the northwestern U.S. So far, five companies have approved of a fluid reuse program, which will begin in the summer of 1985.

VOLUMETRIC ANALYSIS

The following analysis is based on a typical Alberta foothills well using a typical KCl drilling fluid. These wells would be approximately 3 000 m in depth, and in conventional operations, would create a sump at the end of the hole approximately 2 000 m^3 plus 90 m^3 of cuttings. The cuttings would represent 10% solids by weight.

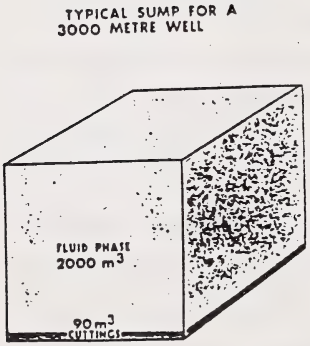


Figure 1

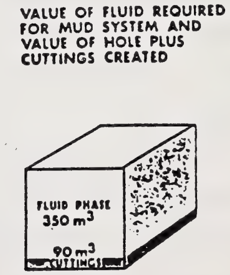

VALUE OF FLUID REQUIRED FOR MUD SYSTEM AND VALUE OF HOLE PLUS CUTTINGS CREATED
FLUID PHASE 350 m3
90 m3 CUTTINGS

Figure 2

Figure 1 is a representation of a sump containing 2 000 m^3 of fluid and 90 m^3 of cuttings. Figure 2 represents the theoretical minimum volume required at the end to complete the hole. This is a cube of 440 m^3, of which 350 m^3 is the fluid phase and 90 m^3 is the cuttings. 150 m^3 of the fluid phase is in the mud system, and 200 m^3 was needed to fill the hole. Thus, 1 650 m^3 of fluid can be deemed excess. The 90 m^3 of cuttings will be created no matter what system is used.

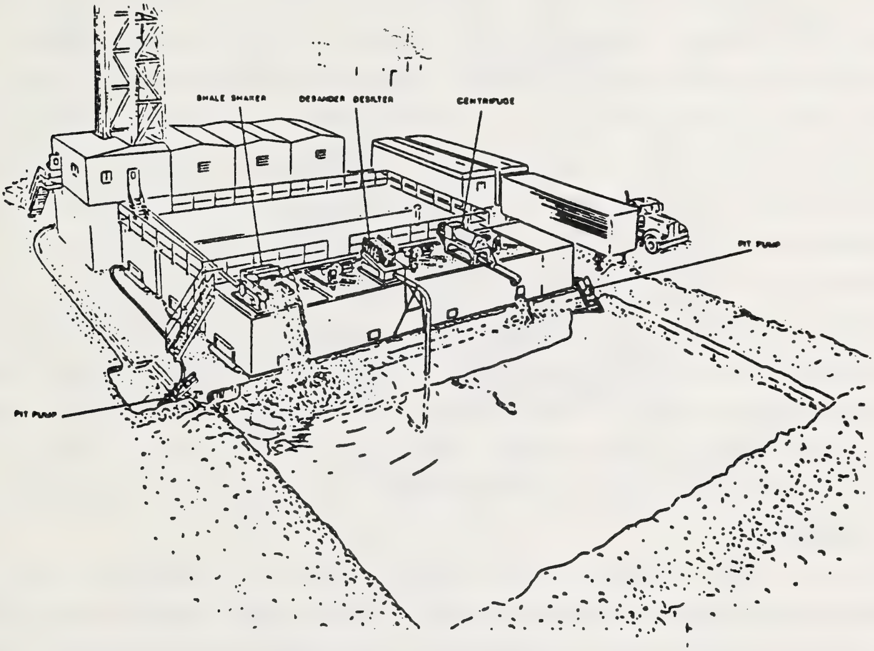


Figure 3

Figure 3 shows a typical, conventional mud system setup. First, the fluid comes back from the drilling operation over a shale shaker where the heavy cuttings are removed and drop into the sump. Sometimes, however, the screen gets blinded and excess fluid flows into the sump. Next the fluid goes into a settling compartment where the heavy sands are settled out. Periodically a door is opened in the bottom of the compartment and the sand trap is dumped into the tank. Because of the manner in which it is dumped, it is approximately 10% solids and it is dumped three or four times a day. Next, the fluid is put into the tank from which fluid is drawn continuously through a desander hydrocyclone. To make the hydrocyclone operate effectively, the sand-bearing underflow is dumped in the pit at about 10% solids.

The finer silts are removed next, in a 20 cone desilter hydrocyclone system. This operates on the same principle as the desander, with about 10% solids coming out in the underflow. Fluid is drawn out of the system on a continuous basis and run through a centrifuge where the final reduction is made of suspended solids. A typical centrifuge can produce a 20 micron or larger underflow. This is about 10% solids going into the pit. Finally, the suspended solids of 20 microns or less are recirculated down the hole, where they cross the bit face, get ground finer, and accumulate with more ultrafines. This accumulation and regrinding process continues until the quality of the mud becomes unsatisfactory, at which time one of the compartments in the mud system is dumped into the sump, and a new batch of drilling fluid is made up to dilute the existing fluid, thus raising the quality to some acceptable standard. Also note in Figure 3 that there is a small sump for the wash water. Most rigs do not even isolate the rig wash water from the sump and allow the rig wash water to go into the sump which can, in some cases, almost double the volume of the sump. Thus we see how the 2 000 m^3 of fluid and the 90 m^3 of solids in a typical sump were created.

In the Hitec process a CEC system allows the drilling fluid to retain its qualities while the cuttings are removed through the use of a unique agglomeration technique. Conventional drilling fluid treatment chemistry is the same as that of most water treatment, requiring the adjustment of pH and the adding of calcium ions to create flocculation and settling of the solids. This is not acceptable with drilling fluids, however, because a specific pH and a strict control of calcium ion molality must be maintained to operate the fluid at its optimum level. Water treatment chemistry cannot be used if the fluid is to be economically reused.

Hitec developed a chemistry that would allow the ultrafines to agglomerate in such a manner that they could be mechanically removed. A unique feature of this agglomeration chemistry is an agglomerate strong enough to withstand the mechanical separation (centrifuging) process but weak enough to allow the entrapped water to be removed from the agglomerate. This agglomerating chemistry was also designed so the dissolved constituents of the drilling fluids were not removed or altered. Hitec was able to develop a chemistry for which no pH adjustment need be done, and calcium ions need not be added. The volumetric analysis, when using a CEC system and reusing the drilling fluids that are left at the end of the hole, shows significant reduction in fluid used, which in turn reduces the disposal problem.

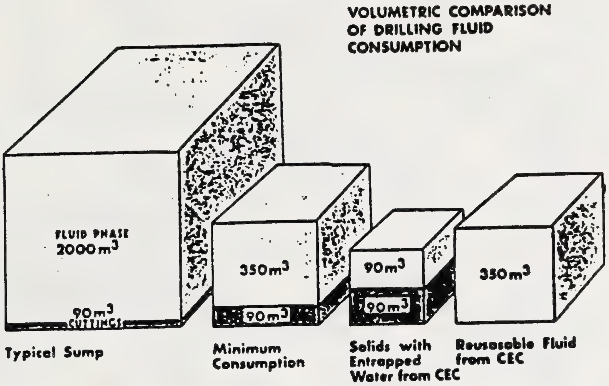


Figure 4

Figure 4 shows four cubes. The first represents the typical, conventional sump, while the second represents the minimum amount of fluid needed to complete a hole. The third cube represents the cuttings and associated fluid left after chemically enhanced centrifuging. The 350 m^3 of fluid left over for reuse are represented by the fourth cube. In centrifuging, a certain amount of fluid is retained by the cuttings, but this can be as low as 50% by volume. In this case, the disposal problem has been reduced from 2 000 m^3 to 90 m^3. If, for some reason, the cuttings can only be removed at 33% by volume, the volume to be disposed of is still only 180 m^3, a five to ten fold improvement over the conventional system.

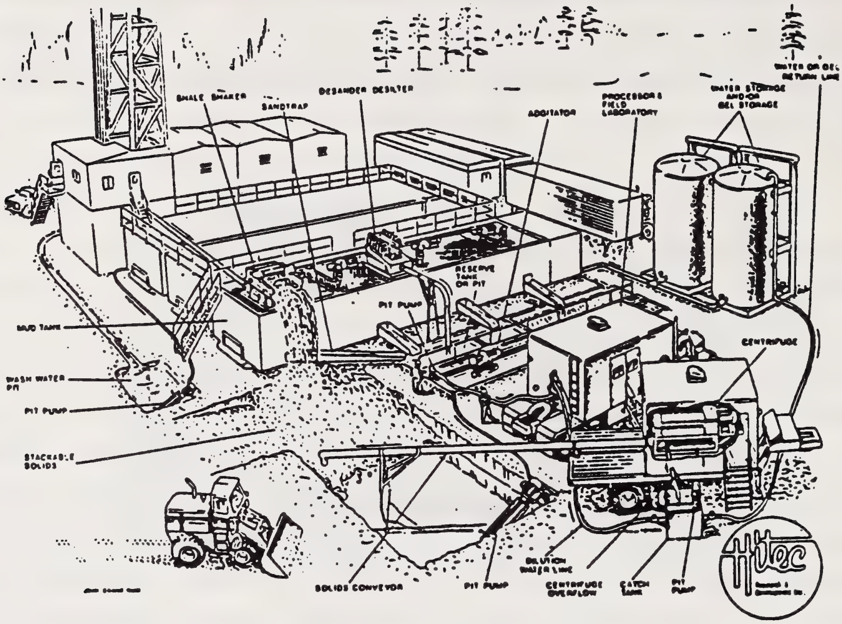
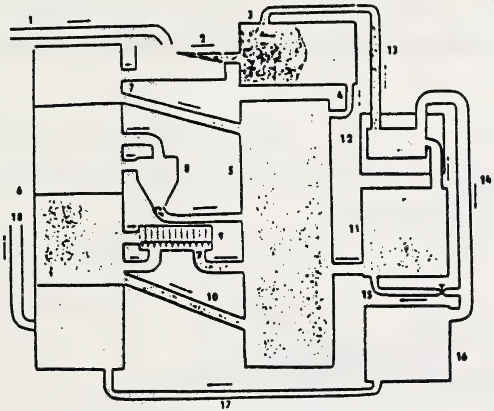


Figure 5

How does a CEC system work? Figure 5 can be compared to a typical layout. The major difference is that to store and drain shale shaker cuttings a very small sloping pit is used. The excess fluid is pumped into a buried tank. This buried tank replaces the sump. Another option is to put the tank above ground but this requires additional pumps. The sand trap, desanders and desilters are dumped into this tank. Whenever the rheology of the fluid becomes unacceptable a mud tank compartment is dumped into the tank. It should be noted that the centrifuge is not required in the mud system, which is a considerable saving to the contractor. Next to the buried tank are the two units for the Hitec system. One is the processor which treats the fluid; the second system is the centrifuge which separates the cuttings from the drilling fluid. In addition, a storage tank for processed fluid is on site. The high capacity and mobility of the Hitec equipment enables it to service three to five rigs on a rotating basis, since the CEC system can generally process five days' worth of contaminated fluid in just one day. The Hitec system is summarized in the flow diagram in Figure 6.

Figure 6



FLOW DIAGRAM OF DRILLING FLUID PROCESSING

1. RETURNED FLUID FROM WELL.
2. SHAKER OVERFLOW.
3. SLOPING PIT.
4. FLUID RETURN.
5. AGITATED HOLDING TANK.
6. MUD TANK.
7. SANDTRAP UNDERFLOW.
8. DESANDER.
9. DESILTER.
10. DRILLING FLUID DISPOSAL.
11. HITEC CHEMICAL PROCESSOR.
12. CHEMICALLY ENHANCED CENTRIFUGE.
13. CENTRIFUGE UNDERFLOW.
14. DRILLING FLUID RETURN.
15. DILUTION FLUID FOR HITEC PROCESS.
16. FRESH DRILLING FLUI STORAGE.
17. DRILLING FLUID MAKI UP.
18. DRILLING FLUID FOR DOWN HOLE CONSUMPTION.

First, the returning fluids, loaded with cuttings, flow onto the shale shaker where the heavy cuttings are deposited into the sloping pit. There they are drained and the fluid pumped over into the buried tank. The underflow of the shale shaker goes into the sand trap where the heavy sands are settled out and dumped into the buried tank at about 10% solids. Then the fine sands are removed by hydrocyclone, and the underflow is dumped into the buried tank at about 10% solids. Next, the fluid is desilted with a 20 cone hydrocyclone desilter, with the underflow dumped into the buried tank at 10% solids, and the fluid returned to the system. Finally, when the rheology of the fluid becomes unacceptable, the fluid is dumped into the buried tank at as low as five per cent solids. From the buried tank the fluid and cuttings are mixed and pumped into the Hitec unit where the agglomeration process is created. The fluid is then put into the centrifuge, where the cuttings are separated at approximately 50% solids, and piled with the solids from the shale shaker, also at least

50% solids. These materials are easily handled by earthmoving equipment. The processed fluid is placed in a storage tank.

In any process of creating agglomerates, there are cases where the amount of contaminant is so great that it inhibits the process of agglomeration. In these cases, the contaminated fluid needs to be diluted. In the Hitec process, the clean drilling fluid from the storage tank or directly from the centrifuge is diverted back into the process, and dilution is accomplished in a closed circuit.

RHEOLOGICAL COMPARISONS BEFORE AND AFTER PROCESSING

The test of success with a closed circuit system is the maintenance of rheological properties of the drilling fluid after the contaminated fluid has been processed.

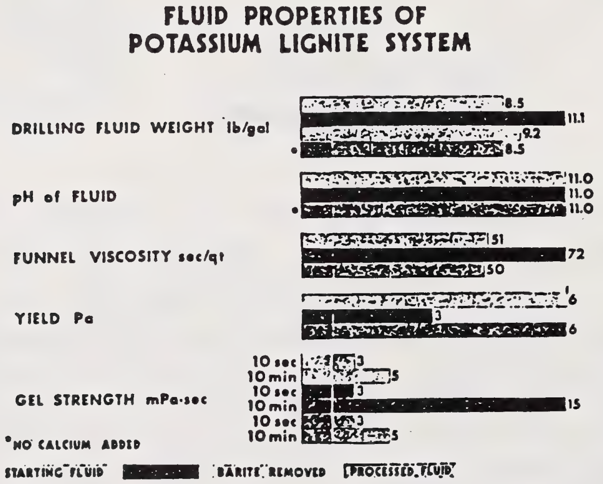


Figure 7

Figure 7 compares the properties of a potassium lignite system before and after Hitec processing. This is a mud weighted with barite. As the drilling proceeded, ultrafines accumulated, causing the weight of the material to increase to 11 lbs. per gallon. After the used fluid was run through a small centrifuge to remove the barite, it was brought into the processor, where the cuttings were removed. This brought the fluid back to its original weight of 8.5 lbs. per gallon. Fluid pH was kept consistent at 11. It is also notable that no calcium ions were added. Original funnel viscosity was 51 seconds per quart. Processing returned this measurement to 50 seconds per quart. Yield in the contaminated fluid fell to three, but processing returned it to the original figure of six. Gel strength at 10 seconds was three in all cases, but at 10 minutes, the used fluid had deteriorated to a reading of 15. Processing returned this to its original figure of five. Thus, Hitec processing restored all of the original rheological properties.

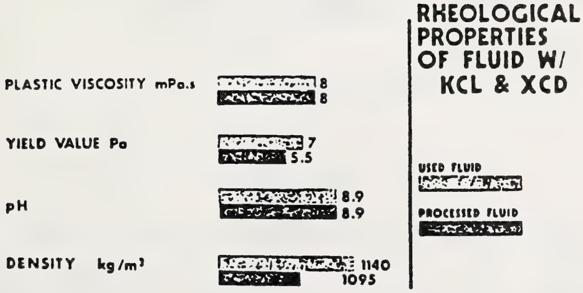


Figure 8

Another example is the rheological properties of a KCl system using XC polymer, as shown in Figure 8. The plastic viscosity remains the same, indicating that the polymer has not been removed by the processor. The yield value has decreased, which indicates the removal of ultrafines, and again the pH did not change throughout the process. Finally, the density was reduced from 1 140 kg/m^3 to 1 095 kg/m^3.

COST CONSIDERATIONS

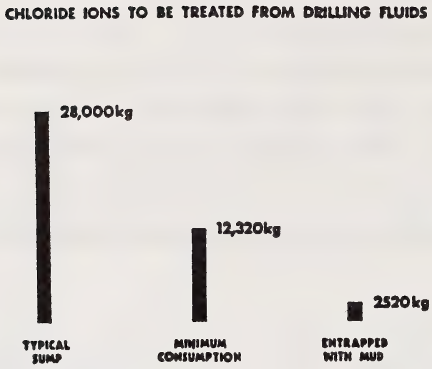


Figure 9

Figure 9 analyses chloride consumption because chloride is the most costly item in creating either a KCl or salt saturated mud. A typical sump has a certain amount of dilution, so that there exists a concentration of approximately 15 000 parts per million (ppm) of chloride ions, or a total of 28 000 kg of chloride ions in a typical sump. In the minimum consumption situation, this would be a saturated solution of 30 000 ppm, meaning a use of only 12 320 kg or chloride ions, a reduction by half. If the 12 320 kg left at the end of the hole are reused, there is no loss, except for the chloride associated with fluid trapped in mud. If this waste mud is assumed to be 50% solids, there is a loss of 2 520 kg of chloride, while a density of 33% solids would mean a loss of 5 000 kg of chloride. The savings are, in any case, on the order of 5 to 10 fold. This reduction applied to all dissolved constituents of drilling fluid costs.

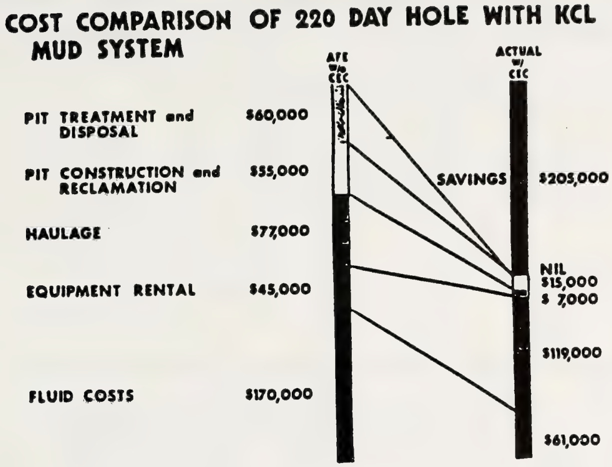


Figure 10

Figure 10 shows a cost comparison for a 220 day hole in the Alberta foothills using a KCl fluid. The comparison is between the AFE originally submitted on the hole, based on conventional fluid treatment, and the actual cost using the Hitec CEC system. All the costs have been indexed to reflect present day costs, rather than the exorbitant drilling costs of earlier years. Budgeted drilling fluid costs was $170,000, while actual cost was only $61,000. Equipment rental was significantly different - the AFE required only a centrifuge, while in fact the entire Hitec unit was used once every five days. Haulage costs were significantly reduced. Instead of using vacuum trucks moving a large volume of material from a remote site, dump trucks were used to remove a small amount of solids, and the fluid was moved to another site. Cost of construction and reclamation of the pit was sharply reduced, and pit treatment and disposal costs was nil. This lead to a saving of almost 50% over the original estimate. The process more than paid for itself while minimizing the environmental impact.

It should be noted that the estimated length of the hole was 220 days, but in fact it took only 188 days to drill. It cannot be shown that this saving of days was exclusively a result of the Hitec process, but the improved properties of the drilling fluid certainly saved time. Drillers experienced faster penetration rates, and Hitec expects to complete studies in the next two years on comparative penetration rates with and without the Hitec process in place.

DRILLING MUD AND BRINE WASTE DISPOSAL IN MICHIGAN

A.F. Crabtree[1]

INTRODUCTION

Oil and gas exploration and production in the Michigan Basin began soon after the initial North American oil discoveries in Pennsylvania and Ontario. In 1886 the first successful Michigan well was drilled near Port Huron in St. Clair County. Sporadic exploration continued until the first commercially successful oil operation began in the City of Saginaw in 1925, marking the emergence of a new industry in the state. Since then, more than 38 500 wells have been permitted and drilled, and oil and gas have been produced from 57 of the 68 Lower Peninsula Michigan Counties. Drilling in the Michigan Basin for hydrocarbons has involved wells as shallow as a few hundred feet to more than 17 000 feet in depth.

In 1981, 31 million barrels of oil and 142 million MCF of natural gas were produced, ranking the state nineth in U.S. oil production and 10th in U.S. gas production.

The Michigan Basin was formerly a large inland sea. Due to restriction and evaporation, thick layers of salt were deposited. One half to 2/3 of the oil wells drilled in Michigan today will penetrate from 200 to more than 2 000 feet of salt formation in reaching the oil bearing strata. For those shallower wells which do not cut salt formations, there is still the possibility of encountering connate brines in sedimentary rocks. Brines are naturally occurring nonpotable waters laden principally with dissolved sodium, calcium, magnesium and chloride. Found in the pore space within these formations, brines will normally be fossil water that were entrapped at the time of the rocks' deposition. Table I shows a comparison of seawater to Michigan oil field brines.

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[1] Assistant Chief, Geological Survey Division, Department of Natural Resources, State of Michigan, Lansing, Michigan, U.S.A. 48909.

Oil wells in Michigan are normally drilled with a water base drilling mud, using fresh water in the upper, fresh water zones and a salt saturated mud in the lower zones where salt is to be encountered. Saturated salt water muds are used to prevent the solutioning of the salt formations and for well control. Oil based drilling muds and air drilling techniques are very uncommon in the state. Oil wells are drilled using both rotary (the most numerous), cable-tool, or a combination of both techniques.

The state's oil and gas permit system began in 1927 with the issuance of permit number 1. Since then, permit numbers have been issued in numerical order, with more than 38 500 issued to date. Approximately 1 200 were issued during calendar 1984. Table II shows the distribution of well permits by date according to the relative depth and percentage of salt beds penetrated. For the period 1927-1968, nearly all of the wells drilled were relatively shallow, penetrating little salt. With the discovery of hydrocarbon-bearing reef structures in the Niagaran formation in 1968, exploration for deeper horizons began, encountering greater amounts of salt. In 1975, oil companies were required to confine their drilling muds and fluids to an earthen reserve pit adjacent to the well bore. In 1981, this reserve pit had to be lined with a 20 mil PVC liner.

The average drilling mud reserve pit contains from 400 to 600 cubic yards of waste material, consisting of rock cuttings, drilling muds and salt. Pits are generally 60' x 30' x 13' filled with seven to eight feet of solids and from 250 to 1 440 barrels of brine fluids. Table III illustrates the volumes of pit brines for wells drilled in 1983, broken down by districts in the state, statewide nearly 28 million gallons of pit brines were handled that year.

In addition to salt solids and fluids handled in the drilling of wells, the production of oil and gas also involves the production of significant amounts of brines. Brine exists in the interstices of each of the 22 producing horizons from which oil and/or gas are produced in the state. The brine is brought to the surface with the hydrocarbons

Table I

A COMPARISON OF SEAWATER TO MICHIGAN OIL FIELD BRINE

SEAWATER*

Ion	Average Value (mg/L)
Sodium (Na++)	10 760
Calcium (Ca++)	413
Magnesium (Mg++)	1 294
Chloride (Cl-)	19 375

MICHIGAN OIL FIELD BRINE+

Ion	Average Value (mg/L)	Approx. Max. Value (mg/L)
Sodium (Na++)	50 000	90 000
Calcium (Ca++)	28 000	75 000
Magnesium (Mg++)	6 000	16 000
Chloride (Cl-)	160 000	250 000

* Collins, A. Gene, 1985, Geochemistry of Oilfield Waters, Developments in Petroleum Science Series, Volume 1, Elsevier Scientific Publishing Co., Amsterday, The Netherlands, page 194.

+ Michigan Geological Survey Division, United States Bureau of Mines, and Cory Laboratory, Inc., 1976, Oil Field Brine Collection and Analysis Program, unpublished analyses of 319 samples.

Table II

MICHIGAN OIL AND GAS DRILLING PERMITS

	Salt Encountered				
Dates	Minor Amounts of Salt		Significant Amounts of Salt		Totals
	Number Permits	%	Number Permits	%	
1927-1968	28 182	100%	---	---	28 182
1968-1975	578	21%	2 149	79%	2 727
1975-1981*	654	18%	3 001	82%	3 655
1981-1984**	787	20%	3 149	80%	3 936
	30 201		8 299		38 500

* Reserve Pits Required

** Lined Reserve Pits Required

Table III

ESTIMATED DRILLING PIT BRINE VOLUMES*
1983

Regulatory District	Wells Drilled	Brine/Pit (bbls)	Total Brine (bbls)	Volumes/District (gals)
Cadillac	248	1 300	322 400	23 540 800
East Lansing	129	300	38 700	1 625 400
Gaylord	115	1 000	115 000	4 830 000
Imlay City	52	1 440	74 880	3 144 960
Mount Pleasant	218	400	87 200	3 662 400
Plainwell	72	250	18 000	756 000
Statewide			656 180	27 559 560

* Herrold, Jeffry E., 1984, The Use of Oil Field Brine on Michigan Roadways, Geological Survey Division, Michigan Department of Natural Resources, Lansing, MI.

and must be separated from them. Common separation methods include gravity, heat, chemical reaction, or a combination of these methods. Approximately 3.82 billion gallons of brine were produced by Michigan oil and gas operations in 1983.

This paper will discuss the methods used in Michigan to dispose of these salt solids and fluids, and requirements for pit containment to reduce the potential for groundwater contamination.

REGULATORY ASPECTS

The Department of Natural Resources of Michigan has a unified structure, including both enhancement/conservation and environmental protection functions under one agency. While some other Federal, state and provincial governments have a separate resource management structure, the unified system in Michigan works more efficiently, I believe. Differences between the traditional resource divisions and the environmental protection divisions are more easily resolved under one directorship.

The prime regulator of the oil and gas industry is the Supervisor of Wells. The Oil and Gas Act of 1939 (PA 61) established the Supervisor of Wells with authority to regulate the industry. As part of that authority, the Supervisor can determine how and where solid and liquid wastes from drilling shall be disposed of. While Act 61 gives broad authority to the Supervisor to regulate this industry from "cradle to grave", other statutes give overlapping authority to other divisions. The Water Resources Commission Act of 1929 (PA 245) regulates discharges and the pollution of any waters of the state; it is under Act 245 that National Pollution Discharge Elimination System (NPDES) permits are issued. Similarly, the Solid Waste Management Act of 1978 (PA 641) provides for licensing of solid waste disposal sites. It has not been the practice to require NPDES or landfill permits for disposal of liquid or solid oil field drilling wastes.

To help make the regulatory process more efficient and to also provide for closer tracking of equivalency between statutes, there is an ongoing effort to provide industry, environmental groups and environmental protection bureau input and advice into the rule and order making of the Supervisor of Wells. For example, Act 61 provides for an eight member advisory board, made up of six representatives from the oil and gas industry, plus two members from the general public. Since 1980 a Mud Pit Task Force made up of industry, environmental groups and state officials have regularly met to review new technology and recommend regulatory changes.

The need for strong regulation of drilling practices in Michigan is especially important in regards to groundwater quality. Most of the state's usable aquifers are not well protected by thick layers of clay or silt and are thus relatively vulnerable to contamination from losses of brines at or near the surface. A regulatory framework of anticipatory regulation (e.g., rules, permit conditions, special requirements) coupled with an active program of remedial regulation (e.g., field inspections, compliance efforts, groundwater investigations) has been developed in the state. The disposal of liquid and solid drilling wastes fits into this framework.

CONTROL AND DISPOSAL OF BRINE WASTES

Brine wastes encountered in the drilling and production of oil and gas wells include drilling fluids, pit brines and production brines. The regulation of each is handled differently.

a. Drilling Fluids

When 20 mil PVC pit liners were first required in 1981, it was hoped that this would resolve the problem of groundwater contamination from drilling operations. Studies conducted by Geological Survey Division staff and by Shell Oil Company at locations where groundwater contamination had been established discovered that not all contamination can be attributed to releases of chlorides from the mud pits. Measurable amounts of brines were being lost to the ground during normal drilling operations. Each time a trip was made brine drilling fluids were lost to the cellars, rat holes and/or mouse holes, all of which were open-ended. For each broken line, leaking mud pump, or slop-over at the tanks, brine was lost to the ground.

Shell conducted studies in the Pigeon River Country State Forest at three well sites where chloride contamination of the groundwater had been detected (State-Corwith 2-12, State-Corwith 1-26 and State-Corwith 1-10). Test results implied that spillage of brine during drilling was responsible for most, if not all, of the contamination at these sites (vs. failure of the mud pit liner). Studies and remedial measures continue in the Pigeon River.

Based on this information, and in an attempt to separate the issues of contamination by mud pits from those by drilling spills, a revised Supervisor Instruction was issued effective 1 February 1985 which required, in part:

> Cellars shall be sealed, rat holes and mouse holes shall be equipped with a closed-end steel liner, or otherwise sealed or cased in such a manner that all fluids entering the cellar, rat hole and/or mouse hole shall not be released to the ground but shall be discharged to steel tanks, the lined reserve pit or the mud circulation system. The cellar shall be sealed on the bottom when conducter or surface casing is set and shall be constructed of cement, concrete pipe or culvert material ... .
>
> Aprons of 20 mil virgin PVC or other equivalent material shall be installed under steel mud tanks and overlapping the mud pit apron, and in ditches or under pipes used for brine conveyance from cellars to pits or to steel mud tanks.

b. Pit Brines

During the years following the 1925 opening of the Saginaw Field, oil field brine was often held in large surface lagoons or smaller earthen pits prior to disposal. While some of these storage sites were lined with clayey soils, many provided no barrier to impede the seepage of brine into the waters of state. Other uses of brine were by the chemical industry as a source of sodium or calcium chloride. With government pressure, the use of brine lagoons faded by the late 1940s. Earthen pits declined in number, replaced by tanks of wood or steel. In 1952 there was a sharp incline in the use of oil field brines by chemical companies and an increase in the use of brines for dust control on roadways. By the mid 1970s open pits could only be used to temporarily hold brines involved in drilling operations. Since 1981, impervious plastic liners have been required for these drilling pits.

Current required practice in Michigan is for the fluids in the drilling muds to be pumped off prior to encapsulation of the pit solids. These pit brines represent nearly 28 million gallons per year (see Table III), and they are used for drilling additional wells, disposed of down approved brine disposal wells, or spread on roads for dust and ice control. The best estimate for 1983 shows that approximately 80% of the pit brines (22 million gallons) were used for road dust and ice control. Table IV and Figure I are illustrative.

Table IV

ESTIMATED GALLONS OF OIL FIELD BRINE USED FOR ROAD MAINTENANCE*
1983

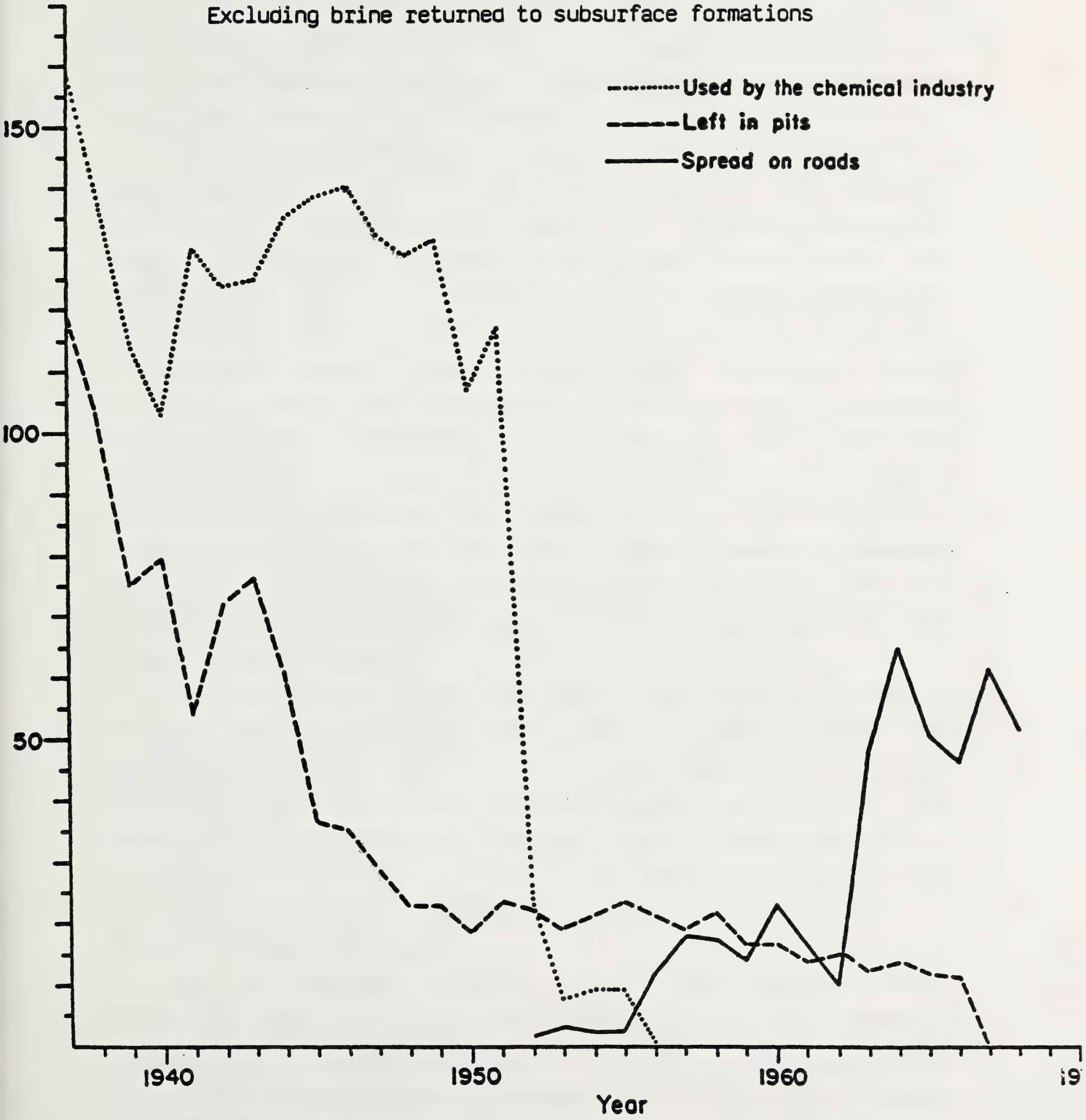
District of Origin	Brine Separated From Produced Oil or Gas	Brine Taken From Drilling Pits	Total
Cadillac	6 837 000	10 833 000	17 670 000
East Lansing	5 028 000	1 300 000	6 328 000
Gaylord	6 071 000	3 864 000	9 935 000
Imlay City	6 285 000	2 516 000	8 801 000
Mount Pleasant	8 186 000	2 930 000	11 116 000
Plainwell	24 344 000	605 000	24 949 000
Statewide	57 751 000	22 048 000	78 799 000

* Herrold, Jeffrey E., 1984, The Use of Oil Field Brine on Michigan Roadways, Geological Survey Division, Michigan Department of Natural Resources, Lansing, MI.

Pit brines have been commonly spread on the public roads and lease roads at little or no charge to the county road commissions. To minimize costs, oil and gas producers tended to dispose of pit brines on roadways near to their well sites. In return for a road

FIGURE I

OIL FIELD BRINE DISPOSAL (1937-1968) *
Excluding brine returned to subsurface formations



*Herrold, Jeffrey E., 1984, The Use of Oil Field Brine on Michigan Roadways, Geological Survey Division, Michigan Department of Natural Resources, Lansing, MI.

commission's permission to spread pit brines on county roads, producers and the waste haulers they hire would spread the brine for free. In this manner, a producer could empty a drilling pit at a minimal cost while a road commission could gain a degree of dust control on county roads without spending any tax dollars.

Since oil field brines have a very low dollar value, the cost of transporting the brine to a disposal site normally outweighs the profit that could be gained through its sale. Brine transporters generally attempt to haul brines a minimal distance from the well site. That desire, in turn, led to frequent brining of the same stretch of road, illegal disposal through dumping into streams, woodlots and gravel pits.

Geological Survey Division staff studies documented several incidences of water well contamination in Michigan with a suspected link to road brining activities. In the past, oil field brines were repeatedly spread on nearby roads. These problems with over-brining and concern for groundwater contamination led to a staff petition to the Supervisor of Wells and two days of formal hearings in November 1984. As a result a Special Order was issued on 29 March 1985 which banned the use of pit brines for dust control (after 1 September 1985) or for ice control (immediately).

There are problems to be worked out by the industry in order to meet this September deadline. While there is enough disposal well capacity statewide to handle the 22 million gallons of brine (487 active BDW), there may also be localized capacity, ownership and other problems which will have to be resolved. Key to the BDW situation is the emerging role of the U.S. EPA in regulating Class II wells under the federal Underground Injection Control program, and all the attendant unknowns and delays.

There are technical problems as well. The suspended solids content of portions of the pit brines may require additional flocculation or treatment to make them compatible with the disposal wells. Different approaches to the problem of solids in the pit brines have been tried with varying levels of success. One company has constructed a three stage settling tank system with a "final filter"; all pit brines go into the tanks and are passed over baffles from one stage to another, until finally being injected down the BDW. In another instance, it has sufficed to rent a steel settling tank and place it next to the BDW to allow gravity separation. Different mechanical separators have been used, including one involving flocculants and a high speed centrifuge, and claiming an extraction rate of 60-65% fluids from the pit solids.

c. Produced Brines

There were 5 476 operating oil and gas wells in the state in 1983. In addition to the oil and gas produced, these wells also produced approximately 3.82 billion gallons of brine. After separation from the hydrocarbons, the greater portion of this brine 98%, was reinjected down approved brine disposal wells. The nearly 57 million gallons (two per cent) remaining were applied for road dust and ice control by more than 40 counties in the state (see Table IV). These 57 million gallons were obtained from approximately 811 wells in the state, or about 15% of the total operating oil and gas wells.

As with pit brines, there have been a number of concerns over the application of produced brines to roads for dust and ice control. These include management to prevent excessive application and the potential for groundwater contamination. Although, under the provisions of a 1981 Supervisor's Order, brine was to be spread only by approved units of government or their agents under the limits of a brine management plan which set rates and numbers of applications, in practice there have been many violations. Reports of injury to roadside trees from road brining as a dust palliative emerged as early as 1936 and continue to today.

Another concern of staff is contamination of soil and water by organic compounds contained in the produced brines. Of 25 wells sampled for benzene, ethylbenzene, toluene and xylenes from 10 different producing horizons around the state in October 1984, apparent inefficient separation of oil from brine resulted in BETX levels as high as 6 900 ug/L benzene, and measurable levels of BETX contaminants in all wells with a valid sample (23 of 25). Five wells showed benzene levels exceeding 1 000 ug/L, and six others had levels exceeding 500 ug/L.

A follow-up study of a heavily brined dirt road in Allegan County demonstrated transport of organics with the brine into the groundwater (see Figure II). Although this exploratory study was not definitive of the statewide situation, it gave the first indication of potential problems from the long standing and essentially unregulated disposal of oil field brines on roads.

Because of concerns over both inorganic and organic constituents and contamination of groundwater, the Supervisor's Special Order of 29 March 1985 also placed these restrictions on the use of produced brines for dust and ice control:

> Effective immediately, produced brines ... shall not be used for ice control purposes.
>
> From July 1, 1985, through December 31, 1986, produced brines may be used for dust control purposes provided:
>
> > produced brines have more than 20 000 mg/L concentrations of calcium
> >
> > produced brines are applied pursuant to a Department approved Brine Management Plan.
> >
> > Concentrations of benzene, toluene and xylene meet the following levels within the respective time frames:
> >
> > > less than 1 000 ug/L from July 1, 1985 - December 31, 1985
> > > less than 800 ug/L from January 1, 1986 - December 31, 1986
> > > less than 500 ug/L from January 1, 1987 - December 31, 1987
>
> On or before July 1, 1985, and annually ... thereafter, [all brine source wells shall be identified and tested for] chlorides, calcium, magnesium, sodium and potassium in mg/L and benzene, ethylbenzene, toluene and xylene in ug/L using EPA protocol for testing ... .
>
> After January 1, 1988, no produced brines shall be used for ice or dust control unless specific rules and standards for these uses are promulgated by the Water Resources Commission.

The January 1, 1988 date is significant, because after that date the only brine that may be spread must be done under the rules and NPDES permit requirements of the Act 245 agency. This is a conscious transferring of authority and responsibility from the resource arm (Supervisor of Wells) to the environmental protection arm of the department.

58th STREET NORTH OF 109
TOTAL BENZENE, XYLENE AND TOLUENE CONCENTRATIONS *

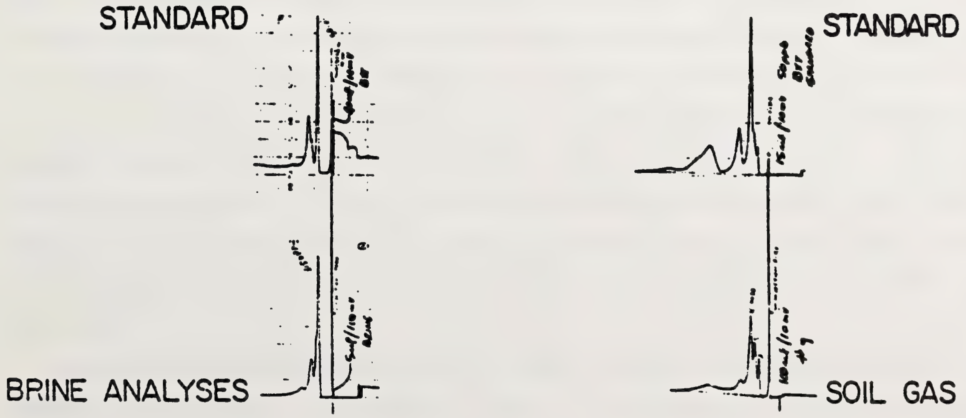
HORIZ. DIST. / DPTH. BELOW SURFACE	100' EAST OF ℄	50' EAST OF ℄	20' EAST OF ℄	℄	20' WEST OF ℄	50' WEST OF ℄	100' WEST OF ℄
1.0'	8.7	84.7	13.3	18.5	12.2	7.6	12.4
2.0'	—	86.8	2.6	17.6	8.7	6.5	—
3.0'	—	20.9	—	9.8	9.8	6.3	—
4.0'	—	12.0	—	—	—	—	—

ALL VALUES µg/LITER

12.0 WATER SAMPLES

BENZENE
TOLUENE
ETHYLBENZENE
XYLENES P.M.O.
STYRENE

ANALYTES



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* Heinzman, James R., 1984, Exhibit 5 Introduced at Hearing Before the Supervisor of Wells, Special Order 1-85, Disposition of Oil Field Brines, Lansing, MI.

CONTROL AND DISPOSAL OF DRILLING SOLID WASTES

Drilling solid wastes consist of rock cuttings and drilling muds, salt solids and entrained salt fluids. No single strategy is effective statewide in providing universal control and disposal of these materials, and several different options are now being used and tested in Michigan.

a. Reserve Pit Construction

In 1975 it became a requirement of the Supervisor of Wells under Rule 304 that:

> Drill cuttings from wells drilled shall be confined by a pit or pits or proper size and construction and located in close proximity to the well bore.

In October 1980, the Department's Task Force on Brines, Salt Cuttings and Brine muds from Oil Drilling Activities recommended:

> That the Supervisor of Wells notify the oil drilling industry that after a specified date, onsite disposal of salt cuttings and brine muds will not be allowed and no drilling permits will be issued unless approvable reuse or disposal systems are identified in the [drilling permit] application or environmental assessment.

Alternative technologies were not then established which would have allowed such a sweeping change, but it was recognized that the present method of in-ground reserve pits and spidering of fluids was contributing to ground and surface water contamination and could not be allowed to continue. Therefore, as an interim measure, the Supervisor issued instructions on 6 April 1981 which provided for a two-pit drilling mud system (one for fresh water muds, the other for salt water muds) and required that all reserve pits receiving other than fresh water fluids be lined with 20 mil PVC or an equivalent liner as approved.

A review of these instructions after three years of use revealed a number of problems. In addition, new technologies had been developed. A revised Instruction was issued, effective 1 February 1985, which addressed spill containment, pit liners, drilling, pit contents, completion and mud pit plots. The primary function of lined mud pits in Michigan today is to act as containment of drilling fluids during the drilling phase. A secondary function is to serve as primary containment of the solids and entrained fluids at encapsulation. This Instruction was intended as an interim measure, as the 1981 ones had been, while further investigations were underway by a Task Force or regultors, industry and environmental groups to evaluate alternate technologies to resolve this problem.

The 1985 Instruction requires that all pits must be lined with an impervious material which will meet or exceed the specifications for 20 mil virgin PVC shown in Table IV. Liners other than 20 mil virgin PVC require written approval prior to use. Specific directions for seams, installation, loading and repairs are also given. After completion of drilling, the reserve pit must be covered with a 10 mil PVC cover (or equivalent) according to specifications (see Table V).

Experience with 20 mil PVC liners is inconclusive. The primary problems with the material as an impervious barrier to migration away from the mud pit of chlorides have been:

- improper pit excavation placing stress on the liner sides, stumps and debris puncturing the liner bottom
- difficulties with installation, especially in cold weather
- field streams and lower grade PVC material (20 mil is not always 20 mil)
- rips and tears during installation and drilling
- improper encapsulation so that the cover does not prevent infiltration from the surface
- the squeezing out of muds during closure
- UV deterioration of liner materials when pits are left open for extended periods
- third party disturbance of a pit once it has been encapsulated

PVC liners that have been exhumed show little physical deterioration from soil burial over a several-year period. Liner manufacturers claim an effective buried life of PVC for 50 to 200

Table V

MATERIAL PROPERTIES

Property	ASTM Test Method	Liner Material	Cover Material
a. Specific Gravity (Minimum)	D792	1.20	1.20
b. Minimum Tensile Properties (each direction)			
1. Breaking Factor	D882-75 Method A or B	46 lbs./in. width or 2,300 lbs./sq. in.	23 lbs./in. width or 1,150 lbs./sq. in.
2. Elongation at Break	D882-75	300%	250%
3. Modulus (force) at 100% Elongation	D882-75	18 lbs./in. width D882-75 or 900 lbs./sq. in.	or 450 lbs./sq. in.
c. Minimum Tear Resistance	D1004-66	6 lbs. or 300 lbs./in. (Graves)	3 lbs. or 150 lbs./in. (Graves)
d. Low Temperature Cold Crack	D1790-76	-15°F	-10°F
e. Dimensional Stability (each direction, % max. change)	D1204 (212°F, 15 min.)	5%	5%
f. Resistance to Soil Burial (120 day soil burial) (% max. change)	D30883 Mod.		
1. Breaking Factor		5%	5%
2. Elongation at Break		20%	20%
3. Modulus at 100% Elongation		20%	20%
g. Bonded Seam Strength (Factory Seam, Breaking Factor)	D3083 Mod.	80% of original material	80% of original material
h. Volatile Loss (% loss max.)	D1203 Method A	0.9%	1.5%
j. Maximum Water Extraction	D1239	35%	35%

From Standard #54, Unsupported Flexible Membrane Liners
National Sanitation Foundation

years, but based on extrapolation of bench tests only. The effective life of the PVC liners is not known.

A problem of great concern in Michigan is the location of mud pits in areas of high water tables. Where the encapsulated pit sits in water, it is subject to hydraulic pressures and there is more likely to be migration of chlorides through the liner membrane from osmosis. The Instruction requires that the bottom of the liner not be installed within the observed groundwater table as determined while excavating the pit. If groundwater is encountered, the pit must be moved: vertically above the water and pit contents stiffened after drilling; vertically four feet above the water; or, laterally to another drier location either at or away from the well site. The operator may also use steel tanks during drilling and dispose of the contents off-site as approved.

b. Reduction of Salt in Drilling Solid Wastes

Key to minimizing the potential for groundwater contamination from encapsulated mud pits is the reduction of salt solids and fluids in the drilling cuttings. This may be done by isolating salt muds and cuttings from fresh water muds (i.e. two-pit system) to reduce the size of the solid waste management problem, by dissolving the salt solids brought up with the drilling muds into salt brines for more effective physical handling, or by employing enhanced technology to extract salt brines from the drilling solids prior to encapsulation.

(1) Two-Pit System

The two-pit system was used more extensively when unlined, fresh water mud pits were allowed. There were some semantic differences, however, about what "fresh water drilling muds" consisted of. The 1981 Supervisor's Instruction stated:

> unlined supplementary earthen pits will be allowed at drilling sites to receive fresh water drilling fluids and cuttings during that period of the drilling operation when only fresh water is used as drilling fluid.

The intent of the Instruction was that only fresh water was to be used. "Fresh water drilling fluids" in the vernacular of the industry, however, means "unsaturated drilling fluids" and may contain significant levels of chlorides. The Petroleum Extension Service of Austin, Texas, notes that "muds are ordinarily classified as saltwater muds when they contain over 1 percent salt (6,000 ppm of chloride ion) ...". A survey of division field staff revealed that "fresh water fluids" commonly contained 1 000 to 2 000 ppm chlorides in the winter time to prevent line freeze-up, and in the summer may contain up to 1 000 ppm chlorides since the fluids are run through the same lines and pumps used in the handling of brine fluids.

The new Instruction eliminates the concept of an unlined fresh water drilling fluid pit and requires all pits to be lined. Regardless of this requirement, the two-pit system remains an option and is used in the state as a method of isolating drilling wastes of high salt concentrations (i.e. when penetrating salt formations) from those of low salt concentrations (i.e. when penetrating fresh water zones and the glacial drift). If for no other reason than reducing the physical handling problem of a relatively large quantity of solid waste, the two-pit concept has merit. It remains an option, however, for the industry, with both vigorous proponents and detractors.

(2) Salt Solids Solutioning

The salt solids and fluids left in the pit along with rock cuttings and drilling muds at some wells could constitute nearly half of the salt solids and fluids which were handled in the drilling of the well. For a well with a standard 7 7/8" drill hole cutting 1 200 feet of salt and using a ten-point-nine brine mud, the salt handled during drilling would be approximately 78 tons.

If the salt solids are allowed to run into the mud pit along with the rock cuttings off the shale shaker, however, it becomes very difficult to later dissolve them and to remove them as brine. Experiments with fresh water washings of the cuttings containing salt solids, in an attempt to reduce the salt content of the cuttings left on site, have been made since 1981 in Michigan, with varied results. After the top fluids are drawn off, fresh water is jetted into the pit to dissolve additional salt solids there. Because of the density of the mud, jetting is not effective in slurrying more than about 1/3-1/2 of the mud column. In this portion, however, and with repeated fresh water washings, a net chloride reduction of 44-80% has been measured.

One way to reduce the amount of salts ultimately left in the pit is to dissolve the salt solids as they are brought up the drill stem to the surface and to remove them as brine. Another method of reducing the amount of salt in the pit is to prevent it from entering the pit in the first place. Both methods work in the same manner; when penetrating salt formations, the solids are diverted from the shale shaker into either a tank for removal from the site as a solid to a licensed disposal facility, or into a solutioning box. The solutioning box is usually a half-tank equipped with a jet pump and a supply of water to keep the salt solids agitated until dissolved. The resultant brines are then circulated back to the mud circulation system or to the reserve pits. At the completion of drilling, these brines are then removed as fluids.

The Supervisor's Pit Liner Instruction requires salt solids solutioning or removal as solids. Measurements of the effectiveness of these techniques have been proposed, but no program is yet underway.

(3) Salt Fluid Extraction

The amount of fluids left in the mud pit after top fluids are drawn off is significant. Experiements have been conducted with hydroclones and centrifugal pumps to remove additional fluids from mud pits, either by reprocessing the pit contents or as add-on units while drilling is taking place. These efforts are successful in removing from 25-60% of the fluids from the solids. The fluids produced are nearly clear and free from suspended solids, and suitable for either brine well disposal ort makeup water for drilling operations. The solids ar stable and easier to encapsulate, and the chloride content is reduced appreciably. Evaluation of the cost and effectiveness of these systems is still underway.

c. Pit Stiffening

Upon completion of drilling an exploratory or development well using the rotary method, the drilling mud and cuttings in the pit have a "toothpaste like" consistency. This has presented problems for the landowner, particularly in areas of low permeability soils and with lined pits. Specific problems which have been reported include reduced load bearing capacity of the ground over the pit and the formation of wet spots over the pit where local drainage has been affected. With lined pits it is necessary to leave the pit open over the winter months to sufficiently "dry" the mud before encapsulation. This may result in increased pumpage of fluids from the pit by the operator or an overflow of fluids from the pit in times of heavy precipitation.

Prior to lining of pits, "spidering" of "trenching" of the pit contents was a common practice. This increased the load bearing capacity making it easier to cover the pit. It tended to become structurally stronger over time. With the requirements that pits be lined, various operators and contractors began adding fillers to the pit to increase the load bearing capacity. Common items included native soils, gravel and sawdust.

In response to this physical handling problem, three operators have developed processes designed to "stabilize" the drilling mud in the state. These processes chiefly involve the addition of cement kiln dust (CKD), cement, aggregate and other materials to the drilling mud and cuttings remaining in the pit after the excess water has been pumped off. Mixing is performed with a backhoe or similar piece of equipment. Jet pumps have also been employed. The product is a stiffened material resembling a low grade mortar, and with great load bearing capabilities. The processes are exothermic and pits can be closed in winter.

Conditioned approval to use these "stiffening" processes was granted to the operators for a trial period while tests were conducted of the materials to insure that toxic materials were not being added to the pits, and of the effectiveness of the processes. A Michigan testing company involved in laboratory testing for one of the operators states:

> The product ... is a solidified matrix capable of passing the Resource Recovery Structural Integrity Test ..., and

> Generally, based on the laboratory studies conducted to date, the process has the potential to significantly reduce the brine migration into the surface and the groundwater ...

Results of tests run by the DNR laboratory on samples of the raw material used to stiffen pits by one operator are included in Table VI. The EPA toxicity test uses water with an acidic pH of 7. On the basis of this data, staff believe that the raw material is suitable for disposal in a Type III landfill, and that addition of the raw material to a mud pit would not introduce toxic materials. Staff were concerned, however, about elevated SO_4 levels in the leachate. Heavy metals are also present in the raw material, but in moderate to low levels.

Preliminary tests of the solidified material have also been conducted. Permeability coefficient values of approximately $1x10^{-5}$ cm/sec have been obtained, indicating a relatively impermeable material capable of resisting penetration of perched water (permeability coefficients were measures using the U.S. Corps of Engineers procedure outlined in EM 1110-2-1906 Laboratory Soils Testing, Appendix VII, Section 7). The ability of the material to resist leaching of chlorides with a perched water hydrostatic head has been measured, but with varying results. Leachate studies run indicated almost complete chloride removal during leaching, indicating that, while there is physical binding in an impermeable mass, there is little chemical bonding of the chloride ions, as would be expected.

Negotiations are now underway with several commercial laboratories to conduct more indepth studies of the pit stiffening process, and to evaluate its effectiveness as a method of improving physical stability and load bearing, and as a method of secondary containment of chlorides.

In the interim, pit stiffening is allowed upon written application and approval by the Supervisor. The Pit Liner Instruction provides:

> Earthen materials shall be mixed with the pit contents to stiffen it sufficiently to provide physical stability and support for the pit cover. A pit stiffening process as approved by the Supervisor may be used at the option of the operator.

Table VI

ANALYTICAL RESULTS OF RAW MATERIAL
USED AS A PIT STIFFENER*

Parameter	Concentration mg/kg	EPA Toxicity mg/L	ASTM Leachate Test mg/L
As	15	--	--
Br	--	--	K 40
Ca	320 000	--	--
Cl	--	--	1 700
Cd	K 2	K 20	K 0.1
Cr	45	K 250	K 0.2
Cu	24	80	K 0.1
Fe	16 000	--	24
Hg	K 0.1	--	--
K	19 000	--	--
Mg	13 000	--	--
Mn	350	--	--
Na	2 200	--	--
Ni	27	K 50	K 0.2
NO_3	--	--	K 40
Pb	62	K 50	K 0.2
Zn	70	K 50	K 0.3

K = actual value less than given. Value given is detection limit at time of test.

* Daniels, J.A., Vugrinovich, R., and Collins, A.B., 1984, Geological Survey Division Actions Regarding Stabilization of Drilling Mud, Geological Survey Division, Michigan Department of Natural Resources, Lansing, MI.

d. Land Farming

Land disposal of drilling solids is a limited option in Michigan due to the very high concentrations of sodium and chlorides in the majority of the drilling muds. Table VII depicts the results from testing five wells in the Wise and Norwich Oil Fields in central Michigan. These wells are 4 400-4 850 foot deep wells in the Richfield Formation, having encountered 200 feet of Detroit River salt formations in drilling. Ther are other wells where up to 1 200 feet of salt is encountered. There are also, however, about 20% of the wells in a given year in Michigan where little salt formations are encountered. An increasing number of these are using a potassium chloride drilling mud.

An application for land disposal of the solid contents (after the fluids are drawn off) of one such well in Calhoun County of southern Michigan has been approved. In the process of drilling the 4 530 foot Grundeman #1 well, the operator used a 4% KCl mud (approximately 300 sax), primarily when penetrating the 325 foot thick Utica Shale section. Chlorides measured at 4 201 feet were 21 482 mg/L with a 7.0 pH.

A modification of the Louisiana application formulas will be used, as well as experience in Michigan with land application of sewage sludge. Formulas used in Oklahoma, Yukon Territory, Northwest Territories and Alberta will also be considered, although the Louisiana formulas appear at this time to be the most conservative. Table VIII is taken from the Louisiana Guidelines.

Staff are now working with the operator to determine spreading rates. Rates of application will be based on the analysis of the pit contents and of the surrounding farmland, considering plant toxicity and groundwater concerns. The operator is now in the process of taking a six-sample composite of the mud pit, analyzed for Ca, Mg, Na, K, Cl, Cd, Ch, Cu, Hg, Ni, Pb, Zn, As, Ba, BETX, EC and pH. Farmland soil samples will be analyzed for pH, Cl, EC, CEC and basic soil fertility.

Under the Louisiana Guidelines, analyses of the pit contents are required to determine limiting constituents (LC) and acceptable loading rates for surface soils. Tests used to evaluate constituents are Electrical Conductivity (EC), pH, Sodium Adsorption Ratio (SAR), Cation

Table VII

ANALYSIS OF DRILLING MUDS FROM WISE AND NORWICH FIELDS

Parameter	Strauch #1	Strauch #2	Strauch #3	Norwich #1	Norwich #2
Barium (ug/L)	K 10 000	3 310	1 450	K 10 000	17 100
Beryllium (ug/L)	K 200	K 20	K 20	K 500	100
Bromide (mg/L)	580	130	-	730	620
Alk. CO_3 (mg/L)	210	160	-	390	290
Calcium (mg/L)	15 100	5 180	6 580	26 600	21 800
Cadmium (ug/L)	K 20	K 20	K 20	K 20	K 20
Chloride (mg/L)	76 800	17 900	-	77 000	59 300
Cobalt (ug/L)	K 50	K 50	K 50	K 50	100
Chromium (ug/L)	K 500	60	50	K 500	100
Copper (ug/L)	6 100	130	150	370	1 100
Iron (ug/L)	61 500	7 300	340	220	17 700
Alk. HCO_3 (mg/L)	17	70	-	5	80
Potassium (mg/L)	1 150	220	499	4 830	3 470
Magnesium (mg/L)	670	380	1.2	2 080	1 970
Sodium (mg/L)	19 400	5 790	8 470	10 000	7 170
Nickel (ug/L)	95	K 50	K 50	K 50	150
Lead (ug/L)	9 900	K 50	K 50	K 50	150
pH	8.9	10.5	9.2	8.4	8.2
Sulfate (mg/L)	640	1 200	-	470	920
Zinc (ug/L)	15 000	90	K 50	K 50	750
Benzene (ug/L)	1 700	210	120	1 900	2 200
Toluene (ug/L)	1 100	170	110	1 500	4 000
Ethylbenzene (ug/L)	-	-	14	160	1 100
Xylenes (ug/L)	-	-	56	540	5 100

Exchange Capacity (CEC), Exchangeable Sodium Percentage (ESP), Heavy Metals and Oil and Grease (O&G). Freeman and Deuel found that mixing drilling muds with surface soils was an environmentally acceptable pit closure method, and contend that the values set forth in their study (a.k.a. the Louisiana Guidelines) are viable and practical for designing pit closures to protect the environment. They studied a total of 293 drilling pits closed in wetland and upland areas using these values, with an average pit closure cost of $17 000. They further state that the six limiting constituents commonly found in drilling muds are salts, oil and grease, lead, barium, zinc and chromium. The limiting constituents expected in Michigan with the KCl muds are salts and heavy metals.

Several test applications are anticipated over the next 6-12 months, with appropriate monitoring and data collection to evaluate this alternative method of waste disposal. While KCl drill mud land disposal is not likely to become a major disposal option because of the number of wells in any given year, if it provides a benefit to the landowners and can be demonstrated to not contribute to unacceptable groundwater contamination or plant/soil toxicity, then it should be available as an option nonetheless.

CONCLUSIONS

Michigan is unique in having both vulnerable aquifers and significant amounts of salt handled in drilling and waste disposal. Organic contamination is another concern. Even within the relatively limited confines of the Michigan Basin however, it is becoming increasingly apparent that there is no universal method of disposing of drilling muds and brine wastes that is both effective and environmentally acceptable. On-site disposal of drilling muds as we now know it, even with the strictest of controls and the optimum of pit liners, is still only a temporary solution to long-term disposal.

The evaluation of several alternative technologies to: (1) reduce the amount of salt handled; (2) reduce the amount of salt solids that must be disposed of, either on- or off-site; and (3) improve the efficiency and reliability of containment methods, are complementary pieces to the puzzle. Hopefully, several different opinions will

Table VIII

GUIDELINES FOR CLOSING DRILLING WASTE FLUID PITS*
UPLAND SITES

Parameter	Max. Before Closure	Max. After Closure
pH	--	6-9
EC (mmhos/cm)	--	4-8
SAR	--	12-20
CEC	--	more than 15
ESP	--	15
Arsenic (ppm)	20	10
Barium (ppm)	5 000	2 000
Cadmium (ppm)	20	10
Chromium (ppm)	1 000	500
Lead (ppm)	1 000	500
Mercury (ppm)	20	10
Selenium (ppm)	20	10
Silver (ppm)	400	200
Zinc (ppm)	1 000	500
Oil and Grease (%)	10	1

* from Freeman, B.D. and L.E. Deuel, 1983, Guidelines for Closing Drilling Waste Fluid Pits in Wetlands and Upland Areas, Shell Oil Company, New Orleans, LA, and Texas A&M University, College Station, TX.

emerge to allow both operators and regulators to dispose of drilling muds and brine wastes efficiently and in an environmentally responsible manner.

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DRILLING WASTE MANAGEMENT BY PUBLIC LANDS DIVISION FIELD STAFF

D.A. Lloyd[1]

My short presentation will cover three areas concerning Public Lands Division's involvement with gel and saline drilling wastes. These are:

1. procedures Public Lands personnel follow and prefer for drilling waste disposal;
2. regulatory considerations and other concerns with drilling waste disposal; and
3. areas for future discussion and potential research.

INTRODUCTION

Public Lands Division is one of two major divisions in the Department of Forestry, Lands and Wildlife responsible for managing the public land in Alberta. The division manages all Crown land in the non-forested areas of the province and is, therefore, responsible for problems such as erosion control, soil contamination, vegetation cover, and any activity that adversely affects the inherent quality of the land.

The Energy Resources Conservation Board (ERCB) was responsible for administering the sump fluid disposal guidelines (Interim Directive 75-2) on public land in the white area. Public Lands Division assumed this role September 1, 1983, because the ultimate impact of fluids is on your resource, the public lands. Because the Division's field staff has such varied professional training, the staff are in a very good position to administer the guidelines.

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PROCEDURES PUBLIC LANDS DIVISION PERSONNEL FOLLOW

What procedures should industry consider for drilling waste disposal? The company must notify our respective Public Lands field offices of any intent to dispose of drilling waste, and then supply pertinent information to our offices before disposal is granted. A standard form is available from each Public Lands field office to facilitate this information exchange. It is important that our office know about the barrels to be disposed of, and the tentative date for when disposal should occur. The form must be filled out for on- or off-lease disposal of any drilling wastes. Off-lease disposal can only occur once the Interim Directive 75-2 guidelines from the board have been met. On-lease disposal does not necessarily require any disposal treatment if, in the opinion of our field officer, the fluids are not toxic and if the fluids can be contained on lease. The sumps that are less than 6 000 barrels can be sampled by Public Lands officers, and the officers can ask for treatment of the sumps if the contents are found to be toxic.

How are sump disposal sites handled by Public Lands field offices? Disposal direction varies from office to office because of soil variation, differing topography, unlike vegetation types and differing water tables. However, the division requires that surface disposal of muds occurs where possible. This may be done by the conventional squeeze process with a cat. The preferred disposal method, however, consists of digging the muds out of the pit with a backhoe and spreading the material out on the lease with a cat, so that the B horizon is mixed with the mud. Until further research provides more explicit guidelines, no more than four to six inches of mud should be mixed with the B horizon. Topsoil would then be placed on top of the soil/mud mix.

A conventional wellsite may not be large enough to permit surface disposal. When a wellsite is applied for, however, a larger area may be taken with the Mineral Surface Lease (MSL) to allow for mud disposal. The spread area that is not part of the original wellsite may be deleted from the lease area by amendment once the muds have been treated, spread and the site satisfactorily cleared by our field officers. The surface disposal option should be quite feasible for single well - single sump locations, depending upon site suitability.

Heavy oil development in the province has produced larger sump volumes in areas such as Peace River and Cold Lake. Again, for those areas in the Public Lands jurisdiction, mud burial is not favored. The disposal methods encouraged are:

a) to completely detoxify both the solids and liquids by reducing the chlorides to 1 000 mg/L and meeting the other board requirements for off-lease disposal and then burying the detoxified material; or
b) to detoxify the liquid component of the muds to board requirements and then land spread the remaining solids. Such spread would likely be tied to the MSL wellsite conditions but be treated as an off-lease disposal situation. Release of the site would occur when soil tests show non-toxic and when physically stable soil conditions exist.

Both in the Peace River and Cold Lake regions, large areas of cleared Crown land are available for surface land disposal of drilling wastes. It is likely that a workable agreement could be reached between industry and the government to allow disposal of drilling wastes on these Crown lands. The major costs involved for such a venture would be transportation and spreading of muds. Breaking of land and discing in of muds should not be more than $100 per acre for both areas.

REGULATORY CONSIDERATIONS

The Oil and Gas Conservation Regulations, notably section 8.1, constitutes the ERCB, and thus Public Lands Division backing for sump fluid treatment and disposal requirements. Contravention of the regulations may cause an order for clean up or may result in prosecution in extreme cases. The **Public Lands Act**, under section 51, indicates generally that no damage shall occur to public land. Under this section, the Minister may order any remedial action required for damaged land. A third area for regulatory control would fall under unauthorized use of land. Should sump disposal occur on Crown lands without any letter of authority, either as a LOC or a field-issued off-lease disposal form, then unauthorized use, under section 47 of the **Public Lands Act**, could be assessed against a company.

All field liaison and activities between government and industry would go very smoothly and would avoid most problems if all pertinent information is provided by industry and government, and if good communication is constantly maintained. Public Lands staff need at least the following:

a) one week prior to commencement of sump disposal, the company is to notify the Public Lands Division district office concerned; and

b) two days prior to treating the fluids, the company is to notify the Public Lands Division district office concerned.

Conversely, Public Lands staff must strive to be consistent when regulating sump waste disposal.

AREAS FOR FUTURE DISCUSSION AND POTENTIAL RESEARCH

1. If land farming of drilling wastes is to occur, then the following areas need to be more clearly defined.
    a) How can the muds be transported most economically?
    b) How can the muds be spread most economically?
    c) How thickly can the muds be deposited and in what form?
        - i.e. a water slurry
        - or a solid wet component
    d) Is a calcium amendment required and, if so, in what form?
        - i.e. a soluble form such as $CaNO_3$
        - or a slow release form such as gypsum
        - or a mixture of both of the above
    e) Should the muds be mixed with the B horizon and topsoil spread on top, or should the mud be mixed in with the topsoil and disced in?
    f) What concentrations of salts and what kinds of salts are to be allowed for a given area?
    g) What other contaminants should be seriously controlled or considered for a land-spreading operation?
2. If muds are to be buried, in what detoxified state should they be buried? What are the toxic chemical parameters that could be safely allowed?

3) And finally, and possibly the most difficult - what board regulations could be considered for amendment and to what degree to ensure a safe environment, and yet allow continued unhindered development of the oil resources?

DEPARTMENT OF ENVIRONMENT REQUIREMENTS FOR LAND DISPOSAL OF INDUSTRIAL WASTES

S. Lupul[1]

INTRODUCTION

In this discussion land disposal of waste is restricted to near surface burial in a landfill, or application into surface soil to effect biodegradation or assimilation commonly referred to as land farming.

When considering these waste disposal alternatives our objective is:

1. to minimize deteriorization of groundwater and surface water quality,
2. to control the changes in soil and site characteristics so that productive use of the site may occur after waste disposal ceases,
3. to minimize closure requirements and post-closure care.

Figure 1 represents practices which we do not condone. Approvals issued by the Director of Standards and Approvals require that facility design and operation be such that the deficiencies depicted in this figure do not exist.

LANDFILL REQUIREMENTS

1. Site Selection

Proper site selection for landfill location generally achieves the desired protection for groundwater and surface water quality at the lowest cost and with a minimum of post-closure care requirement.

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[1] Head, Industrial Wastes Branch, Standards and Approvals Division, Alberta Environment, Edmonton, Alberta.

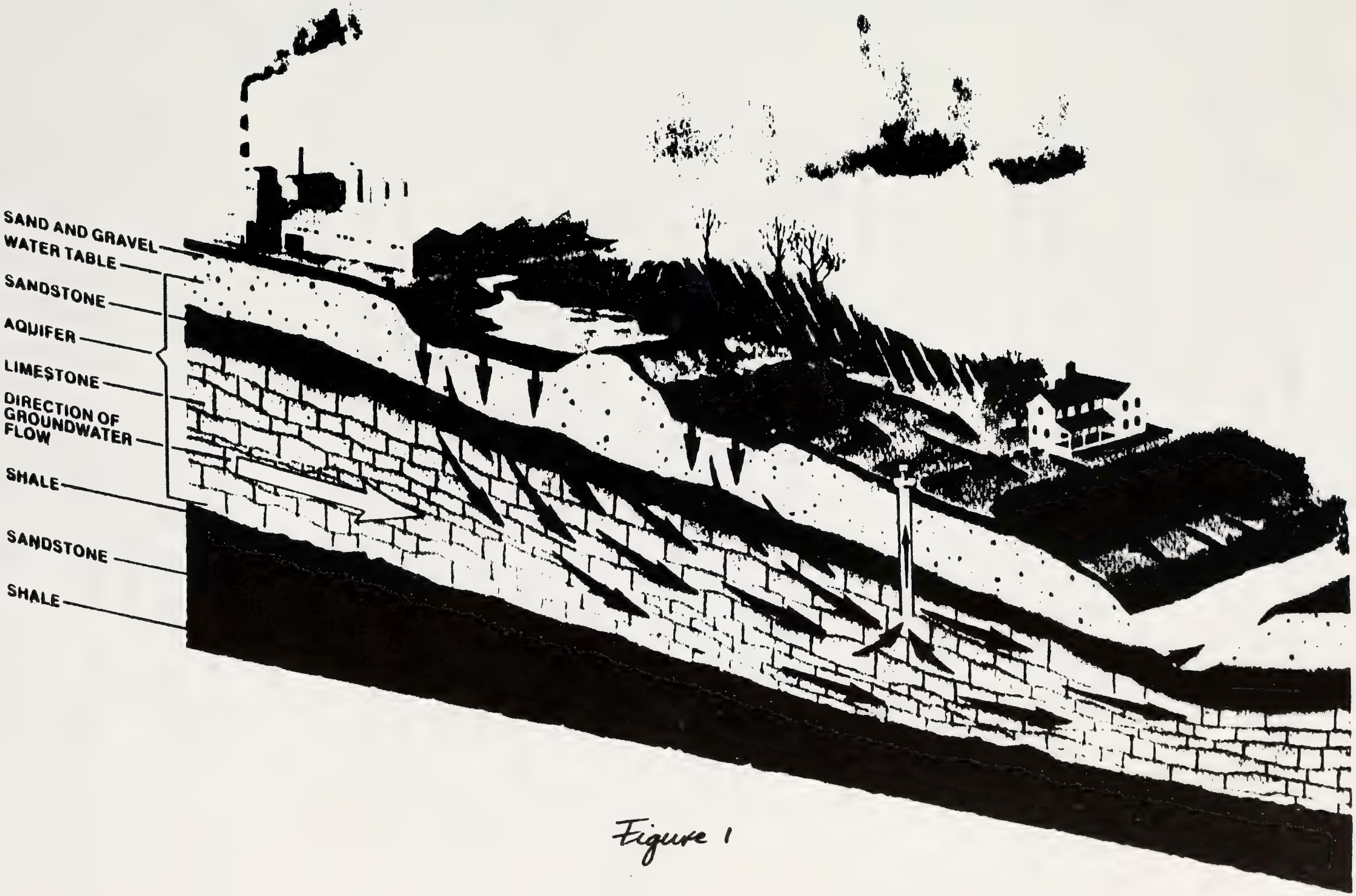

SAND AND GRAVEL
WATER TABLE
SANDSTONE
AQUIFER
LIMESTONE
DIRECTION OF GROUNDWATER FLOW
SHALE
SANDSTONE
SHALE

Figure 1

Site selection criteria includes topography, geology, hydrogeology and proximity to people. The applicable criteria for each of these factors are the following:

(a) Topography

Desirable	Level to undulating to gently rolling plains.
Unsuitable	Steep slopes, depressions where water accumulates, ravines and gullies, stream/river terraces and floodplains, lakeshores.

(b) Geology

Desirable	Materials likely to exhibit hydraulic conductivities of 10^{-7} cm/s or less, e.g., unweathered lacustrine clay deposts and unweathered clay till.
Unsuitable	Materials with a high hydraulic conductivity (10^{-5} cm/s or greater), e.g., sand, gravels.
Questionable	Materials likely to exhibit an hydraulic conductivity in the range of 10^{-7} cm/s, e.g., weathered till; lacustrine silt; and lacustrine, fine-grained, well-graded sands.

The thickness of native material could consist entirely of surficial or bedrock materials, or combinations thereof. The desirable thickness of low permeability material is greater than 15 m. It should be noted that the thickness of aquicludes or aquitards (non-aquifers) assumes less importance in areas of lateral groundwater flow, and lesser importance still in groundwater discharge areas.

(c) Hydrogeology

Aquifer Yields:

Desirable	Areas underlain by aquifers, either surficial or bedrock, where the apparent 20 year yield (Q_{20A}) is less than 5 igpm (20 L/min).
Unsuitable	Areas underlain by aquifers where the Q_{20A} exceeds 25 igpm (115 L/min).
Questionable	Areas underlain by aquifers where the Q_{20A} lies in the range of 5-25 igpm (25-115 L/min).

Groundwater Flow:

Desirable	Discharge areas where it can be demonstrated that surface water will not be affected by mobilized contaminants. Transitional areas (lateral flow) where there will not be significant lateral transfer of mobilized contaminants.
Questionable	Groundwater recharge areas.

Depth to Watertable:

Desirable	Areas where the vertical separation between the seasonal high watertable and the trench bottom is less than 1.5 m.

(d) Proximity to People

Having due regard to the Provincial Board of Health Regulations a landfill is not to be located closer than 500 m from dwellings occupied by individuals not associated with the landfill development.

2. Engineered Features

When a landfill must be developed in a location where the geology is questionable or unacceptable, then engineered features are to be incorporated into the design to achieve our objectives.

An example of this type of design is presented in Figure 2. It incorporates a clay liner compacted to a permeability of at least 10^{-7} cm/sec, a leachate collection and removal system, and a cover which will minimize infiltration of surface water into the waste repository. The design would be tailored for a specific location with due regard for climatic conditions, geology, hydrogeology and the type of waste to be handled. Leachate collection would be required if liquid wastes of substantial quantity were to be accepted in the landfill.

Surface water diversion structures may also be required if warranted.

3. Monitoring

The background quality of groundwater and surface water in the potential zone of influence of landfills is to be determined prior to commencement of operation and continued twice yearly during the operating life. Analyses that are to be conducted include pH,

INDUSTRIAL LANDFILL CROSS-SECTION

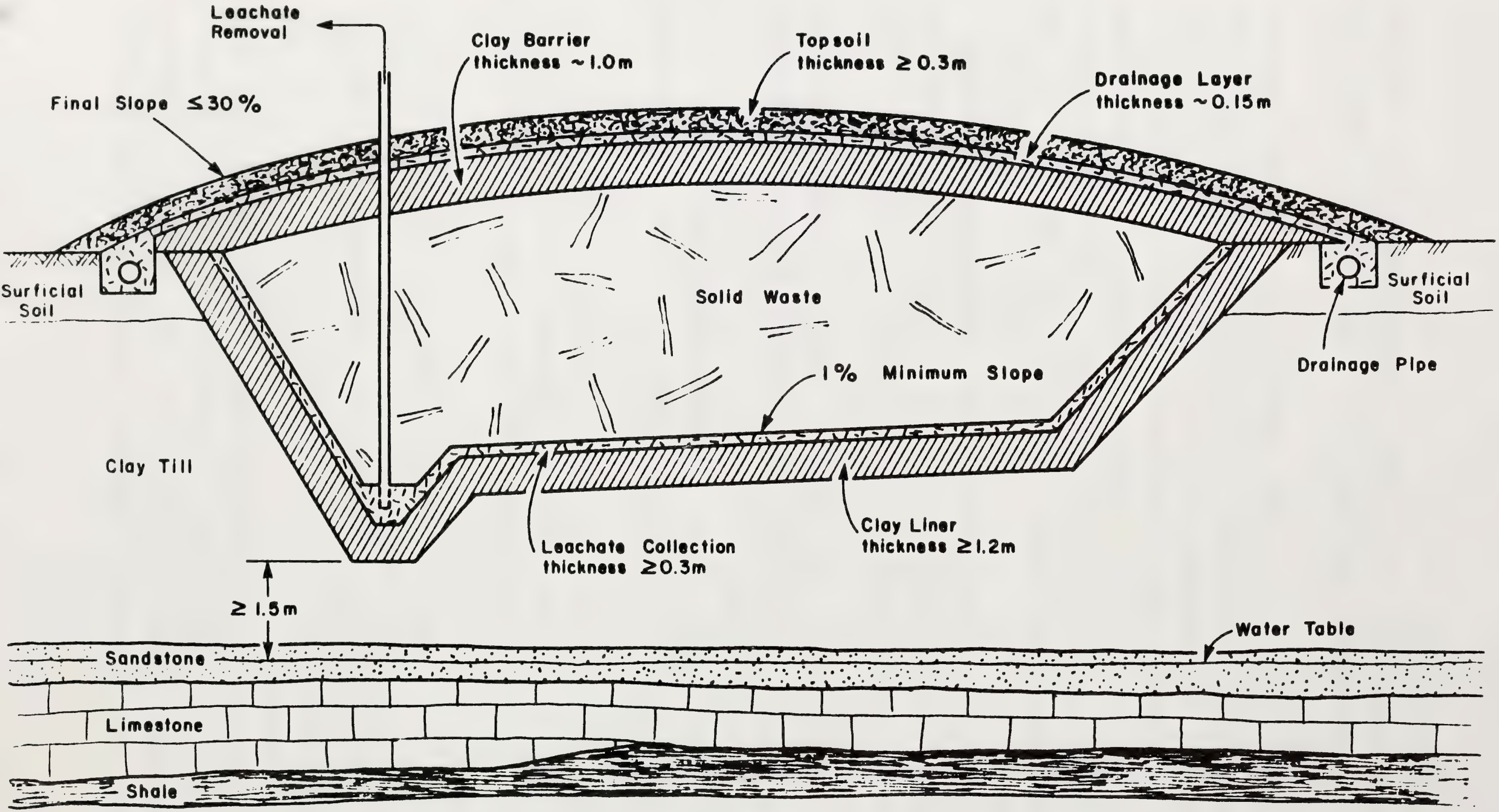


Figure 2

major ions (calcium, magnesium, sodium, potassium, chloride, carbonate, bicarbonate, nitrate and sulphate), electrical conductivity, total organic carbon, total dissolved solids and other specific tests prescribed as a result of specific wastes being accepted.

4. Special Provisions

The new program on hazardous waste management will result in a ban on landfilling certain wastes, as the Swan Hills treatment plant will provide an alternative which was not available in the past.

However, in spite of the lack of a treatment alternative to landfilling we have restricted disposal of certain wastes to landfill or have required special handling to minimize impact of the waste.

For example wastes that contain sulphur must be co-disposed with adequate limestone to neutralize acids produced by bacterial conversion of the sulphur.

PCB waste is being stored as no landfill disposal is permitted.

Encapsulation of waste prior to landfill disposal is required for asbestos.

These kinds of decisions are made based on a knowledge of waste characteristics, assessment of their behaviour in the landfill and implementation of procedures which will mitigate negative impacts.

5. Closure

The decision on closure requirements will depend on the land use plans for the site. This may result in the landfill contents being removed for burial elsewhere, as occurred at a former plant site near Calgary. On the other hand, removal of the waste may be impractical and therefore the land use would be constrained to the extent necessitated by the presence of the landfill. The final coverage requirements would be tailored to fit the use to be made of the site.

The requirements for plant site closure and abandonment are presently under development. Those requirements will also apply to landfills.

6. Application for Approval

Appendix I outlines the specific information that is to be provided in support of an application for a landfill which would be approved under the Clean Water Act.

LAND FARMING REQUIREMENTS

1. Design and Operation

An example of a landfarm established for the treatment of oily sludges produced in a refinery is shown in Figure 3. This design was a result of conditions imposed in a Permit to Construct that was issued by the Director of Standards and Approvals.

The permit required that

(a) the area used for waste treatment was to be graded to provide a slope of 0-5%,

(b) a dyke be provided around the perimeter of the landfarm to segregate contaminated and non-contaminated surface water,

(c) a catch basin be provided to collect runoff from the treatment area,

(d) a groundwater monitoring system be provided consisting of an observation well which yields background quality data, and at least two observation wells located to identify potential impacts on the uppermost water-bearing strata.

The Licence to Operate requires that:

(a) the application rate of oily waste be limited so that after incorporation of waste the oil content of the top 15 cm of soil not exceed 4% by weight,

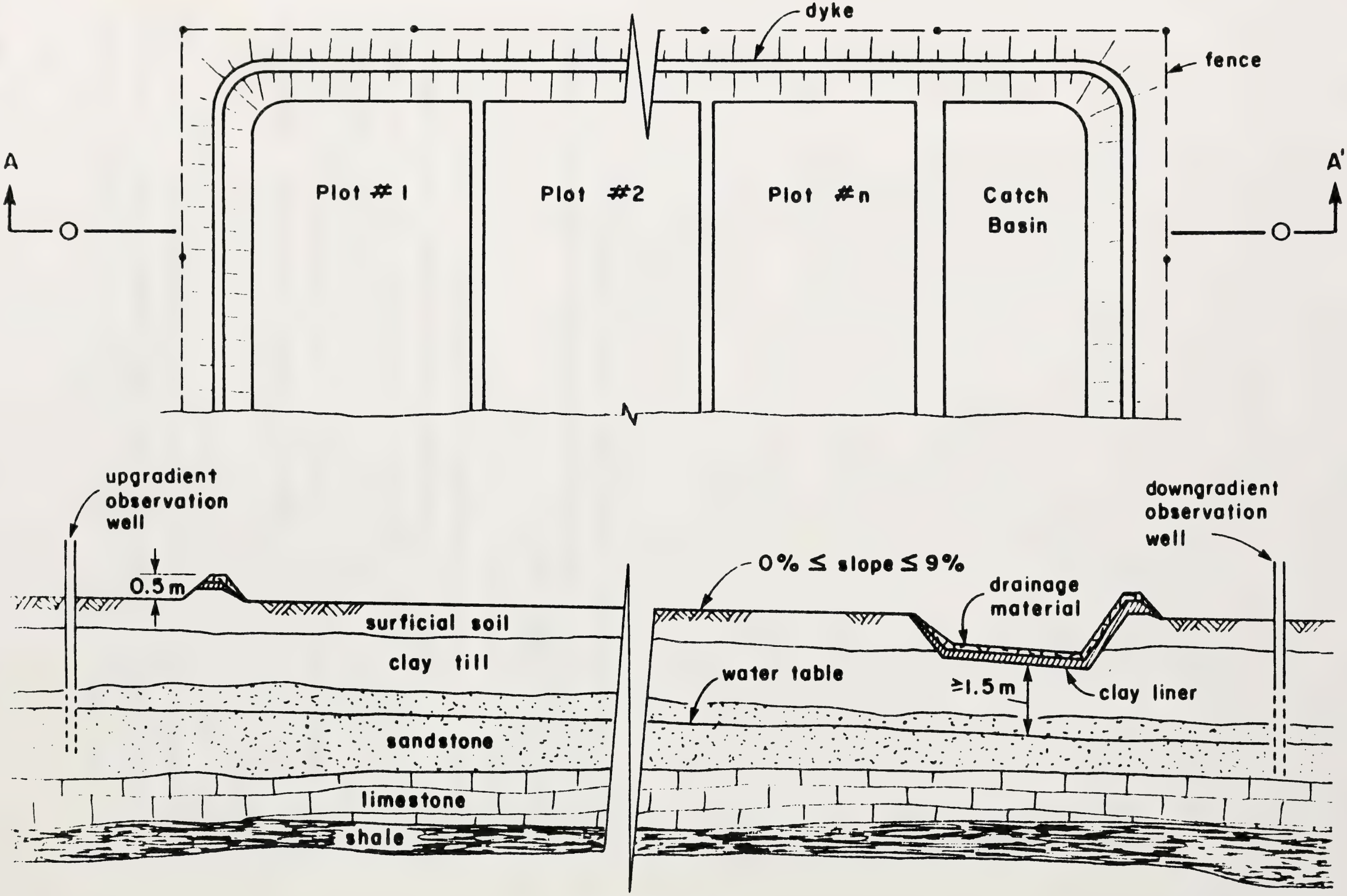
(b) waste shall not be applied when the soil is frozen or snow covered,

(c) monitoring be conducted on the groundwater and the soil in the treatment area.

The above example represents a very specific case we have had to deal with quite recently. The results of the monitoring will provide us valuable information on the effectiveness of the approach for treatment of the specific waste and the impacts on groundwater and soil.

LAND TREATMENT SITE

GENERAL PLAN & CROSS-SECTION



SECTION A-A'

The design shown in Figure 3 is not to be taken as the only acceptable one. Deviations from this approach would be accepted provided that the overall objective of groundwater and surface water quality protection is achieved.

2. Closure

As mentioned for landfill closure, the area devoted to landfarming will have to revert to a safe productive use after the waste treatment ceases. The presence of specific contaminants (e.g., heavy metals) which will accumulate in the soil to levels which are harmfull to vegetation, or to animals that consume the vegetation, must be identified and decisions on closure will be made within this context.

3. Application for Approval

Appendix II outlines the information to be supplied in support of an application for approval of a landfarm development.

APPENDIX I

APPLICATION FORM FOR APPROVAL OF AN INDUSTRIAL LANDFILL

Application No.: ____________

Date Received: ____________

1. General Information
   1.1 Date of Application: ______________________________
   1.2 Name, address and phone number of applicant: ____________
   ____
   1.3 Name, address and phone number of owner/operator: ________
   ____
   1.4 Legal land description of disposal site: ____________
   ____
   1.5 Summary of project: ______________________________
   ____
   ____
   ____

2. Design Considerations
   2.1 Production rate of each waste and concentration of components;
   2.2 Physical and chemical properties (hazards, if any, associated with the waste);
   2.3 Detailed design and description of disposal methods;
   2.4 Physical and chemical properties of the materials to be used as liners, buffers, and intermediate or final covers;
   2.5 Potential of materials described in 2.4 to retard movement and/or provide neutralization of hazardous components of the wastes.

3. Hydrogeological Characteristics
   3.1 Water table level;
   3.2 Groundwater flow directions and rates:
   3.3 Background quality of groundwater within the expected zone of influence;

3.4 Distances of water sources (ground and surface water) from the disposal site;

3.5 Present and future groundwater uses which could be affected.

4. Geographical and Geological Characteristics

4.1 Topography of the area;

4.2 Landfill boundaries and land use of the area;

4.3 Surficial geology (classification, permeability and moisture content of the soil);

4.4 Bedrock geology.

5. Details of the Monitoring System

6. Reclamation of the Site

6.1 Closure and post closure procedures:

6.2 Future use of the site.

7. Local Authority Approval

7.1 Provide one copy of development permit.

APPENDIX II

INFORMATION REQUESTED AS PART OF AN APPLICATION FOR A LAND TREATMENT SITE

1 General Information

- Name, address and phone number of applicant and owner/operator
- Legal land description of treatment site
- Description of project

2 Hydrogeological Characteristics of the Site

- Water table level
- Groundwater flow direction
- Background quality of groundwater in the uppermost water-bearing strata within the expected zone of influence
- Distances to water supply sources (ground and surface water) from the land treatment site
- Present and future groundwater uses which could be affected

3 Geographical and Geological Characteristics

- Topography of the area (slope between 0-5%)
- Land treatment site boundaries and land use of the area (scale diagrams)
- Surficial soil geology (classification, structure, distance to bedrock, etc.)
- Chemical/physical characteristics of surficial soil (zone of incorporation of the waste)

4 Design and Operating Considerations

- Characterization of waste to be applied (H/C, heavy metals)
- Application rates, frequency, etc.
- Nutrient amendments
- Slopes, dykes, runoff collection and containment, perimeter fences, etc.

5 On-going Monitoring and Reporting

- Groundwater monitoring (up and down gradient of the treatment site)
- Soils monitoring
- Reporting: samples collected biannually, analyzed and forwarded to the department

6 Closure Measures, Final Land Use, Reclamation ...

7 Local Authority Approval (Development Permit)

DRILLING WASTES AS A SOILS COMPONENT

C.J. Palmer[1]

INTRODUCTION

Land application of wastes has been shown to be an economically and environmentally acceptable method for the disposal of many waste materials. In addition, wastes can often serve as amendments to improve the productivity of soils to which they are added.

Not all wastes are suitable candidates for land disposal. Even wastes that are normally considered appropriate for land disposal can cause degradation of local soil and water resources if not properly managed. In order to avoid these problems, it is important to understand soil processes and how waste material might interact with soils.

There are many factors that affect the suitability of land application as a method for disposing of wastes. A principal objective of this paper will be to identify these factors. A second objective of this paper will be to evaluate a saline drilling waste from Alberta as to its suitability for disposal by land application.

LAND APPLICATION OF WASTES

The application of wastes to land is most appropriate for situations which result in soil and associated surface water or groundwater resources of equivalent or improved quality. Conversely, land application of wastes should be considered inappropriate when degradation of these resources results. A necessary condition for an assessment of land application of wastes is the ability to measure changes in the quality of soil and water resources.

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[1] Section Head, Soil Chemistry and Physics, Soil Protection Branch, Environmental Protection Services, Alberta Environment, Lethbridge, Alberta.

Water quality standards have been published and guidelines are available to assist in the assessment of potential changes resulting from the land application of wastes. For most situations, effects on surface water resources due to runoff can be minimized through proper management and site selection for land disposal. Consequently, the primary concern when considering land disposal of wastes is the effect this practice could have on soil quality or soil productivity and the underlying groundwater quality.

The measurement of soil quality has received considerable attention yet must still be considered a rather inexact science. One method of measuring soil quality is through crop yields. A disadvantage of this method is that the productivity measured is highly dependent on the crop grown, the management the crop receives and the interaction of the crop with soil and climate factors.

A different approach to the measurement of soil quality is to consider individual soil properties. An assessment of overall soil quality can then be made by comparing each soil property against accepted standards. These standards are established after considering the climate, crops and management practices for a given region. An overall assessment can then be derived by identifying the soil properties that are most limiting to soil productivity. This approach has been suggested for evaluating soils before and after reclamation activities on drastically disturbed lands in Alberta (Alberta Soils Advisory Committee, 1981).

As an example, consider an area that has a continental climate with warm summers and cold winters, where the major portion of the precipitation falls during the growing season (although periods of moisture deficiency are common), and where forage and small grain crops predominate. Several soil properties along with the respective soil quality ratings are listed in Table 1 (Alberta Soils Advisory Committee, 1981). These soil properties are important because each one can be a limiting factor to crop growth. Soil pH can affect the availability of nutrients to plants and whether or not phytotoxic elements such as alumium are present (e.g., pH's below 5.5). The salinity level indicates whether or not the osmotic effect of salts in the soil reduce plant availability of water enough to affect crop growth. The sodicity hazard (as measured by the sodium adsorption

Table 1

CRITERIA FOR EVALUATING SUITABILITY OF TOPSOIL MATERIALS FOR REVEGETATION IN THE PLAINS REGION OF ALBERTA

Rating/Property	Good(G)	Fair(F)	Poor(P)	Unsuitable(U)
Reaction (pH)	6.7-7.5	5.5-6.4 & 7.6-8.4	4.5-5.4 $ 8.5-9.0	4.5 & 9.0
Salinity (E.C.) (dS/m)	2	2-4	4-8	8
Sodicity (SAR)	4	4-8	8-12	12
Saturation (%)	30-60	20-30 60-80	15-20 80-120	15 & 120
Texture	FSL,VFSL, L,SL,SiL	CL,SCL, SiCL	LS,SiC, C,S,HC	
$CaCO_3$ Equivalent (%)	2	2-20	20-70	70

SOURCE: Alberta Soils Advisory Committee, 1981, p. 26.

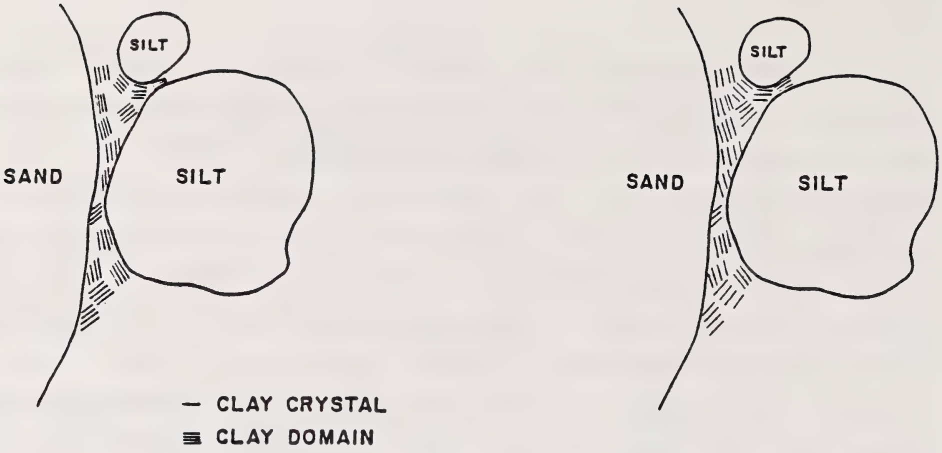
ratio or SAR) estimates the potential for changes in the physical structure of soil with the accumulation of sodium. Water movement in soil is confined to the pore space between sand, silt and clay particles (Figure 1a). The addition of sodium can result in clay swelling (Figure 1b) and clay migration and plugging of pore space (Figure 1c). The net effect is a reduction in the ability of soil to accept or transmit water. Other effects may include reduced aeration or an increased resistance to root penetration. These effects can often be overcome through the addition of calcium amendments such as gypsum that can lower the SAR value and promote flocculation of the clay (Figure 1d).

The water content in a saturated soil paste or saturation percentage (SAT %) of a soil gives an indication of physical characteristics of a soil. The SAT % is approximately double the moisture content that a soil can hold after it has been saturated and allowed to drain freely (field capacity). A low SAT % is indicative of sandy soil with a low moisture holding capacity. A high value for SAT % indicates a soil with a considerable amount of swelling clays and/or sodium content with accompanying adverse physical characteristics of poor tilth, infiltration rates, aeration, etc. In many ways, the SAT % is a useful integrator of several other soil properties.

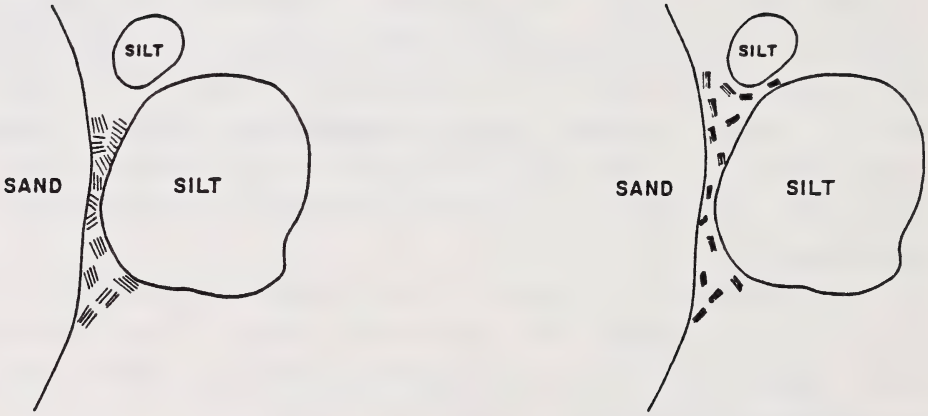
Soil texture is a measure of the relative proportions of sand, silt or clay in a soil. The productivity rating of soils according to their texture is a very subjective process and must take into consideration the crops and climate of a region.

The calcium carbonate equivalent should also be included in an assessment of soil quality for two reasons. An excessively high lime content can interfere with the ability of a soil to supply nutrients, particularly phosphorus. On the other hand, the presence of lime in a waste could serve as an amendment to improve acid soils by raising their pH.

Other properties of a waste must be considered including specific contaminants which could be in sufficient quantities to be toxic to plants or animals. Of specific concern are heavy metals, some organic compounds, and certain anions such as boron or chloride. In many situations, the concentration of any one of these compounds could limit



(a) IDEALIZED SOIL (b) SWELLING



(c) CLAY MIGRATION AND PLUGGING (d) FLOCCULATION

Figure 1. Conceptual diagrams on the role of sodium in clay swelling and migration in soils.

the amount of wastes that could be added to a given area (Overcash and Pal, 1979).

A description of the quality of wastes and soils can be used to address the problem of land application of wastes through the following equation:

Waste + Soil = Amended Soil

The first step in this process is to list soil quality criteria for the area of interest. The next step is to decide if the waste could be considered as a soils component. If the waste has a significant solids fraction, then it should be analyzed as if it were a soil and compared against the criteria established for the soils of the region. This procedure can assist in identifying components of the waste which might improve or reduce the quality of the soil to which the waste is applied. The next step is to determine the quality of the soils being considered as land application sites. This is again accomplished through a comparison to the soil quality criteria. Additional factors such as soil depth, general slope of the disposal area, proximity to surface streams or ponds, and depth to groundwater need to be evaluated at each potential site. The next step is to predict the composition of the amended soil when considered in combination with the waste. Particular attention must be given to selecting waste amendment rates. By selecting several rates, one should obtain a range in potential amended soil qualities. Each of these rates of application can then be evaluated against the soil quality criteria for the selection of the most appropriate rate. The final results should be tested in laboratory and field test trials before full-scale land application efforts. This ensures that all important factors are considered and the theoretical principles are appropriately applied.

The disposal of oilfield wastes is a very important topic in Alberta. The ideas presented will now be applied to a KCl drilling mud waste disposal problem.

KCl Drilling Mud Waste

The value for each property of the KCl drilling mud waste is listed in Table 2. The rating for each of these properties was determined by using the rating guide presented in Table 1. The two components which most limit the suitability of this waste for land farming are the salinity and sodicity. A comprehensive study of all potentially toxic components was not completed. For the purposes of this paper, it will be assumed that no toxic components are present in significant amounts. However, it is recommended that this portion of the study be completed before land trials are undertaken.

Soil

The selection of a soil for land application of wastes should include consideration of two factors. Of prime importance is the proximity of the soil to the location of the waste. Transportation of large volumes of wastes over long distances can be cost prohibitive. The second factor is the kind of soil which could possibly benefit the most from the application of the waste yet not be adversely affected by detrimental aspects of the waste. In this case, one would ideally look for a soil that could benefit from the positive aspects of the KCl drilling waste such as its loam texture, neutral pH, moderate lime content and the presence of KCl fertilizer.

Several soils are available near the location of these wastes as land application sites. Data from a soil survey report for one such soil is listed in Table 3. This soil is non-saline, slightly acidic and low in sodium content. A value for the SAT % for this soil was not available from the soil survey reports but is estimated to be less than 30%.

The limiting property of this soil is its true sandy texture which limits its ability to store plant available moisture and nutrients.

Table 2

PRODUCTIVITY RATINGS FOR A KCl DRILLING MUD WASTE AS A SOILS COMPONENT

Property	Value	Rating
Reaction (pH)	7.5	Good
Salinity (E.C.) (dS/m)	51	Unsuitable
Sodicity (SAR)	67	Unsuitable
Saturation %	62	Fair
Texture	L	Good
$CaCO_3$ Equivalent (%)	12	Fair
Toxic Components	To be evaluated	

Amended Soil

The final term in the equation of waste plus soil is the resultant amended soil. The properties of the amended soil must be considered when determining if a waste can be disposed of through land application in an environmentally safe manner. For this situation, the productivity potential of the soil amended with KCl drilling waste could be improved for the properties of pH, SAT % and texture. The benefit of the lime content of the waste would depend on the pH of the actual soil at the site selected for waste treatment. In any case, an increased lime content would make this soil less susceptible to acidification from fertilizers or acidic atmospheric deposition. The addition of clay and silt fractions in the waste could raise the SAT % and improve the ability of this soil to store and supply moisture and nutrients for plant growth.

The potentially adverse effects of the waste would center on its sodicity and salinity. For this soil, the concern from sodicity would not be with the coarse textured surface horizon; but rather, with the heavier textured B horizon. Accumulation of sodium in this layer could create a layer impervious to water movement similar to that encountered in Solonetzic soils. However, the effects of the sodicity could possibly be counteracted through the addition of a calcium amendment such as gypsum.

The problem of the high salt content could be addressed in several ways. It is not known presently which method would be most feasible. One approach is to apply the waste so as not to cause any concern with soil or groundwater contamination. The difficulty with this approach is that salt content of the waste is so high that only a small amount of waste could be applied in any given area. The consequence is that large areas of land are required, new technology has to be developed for spreading the waste in a thin layer (probably less than one millimetre) and the potential benefits of the waste to the soil would be minimal.

A second approach is to test to see if the salinity of the amended soil might exceed the recommended limits. A one-time mixing of the saline waste with a sandy soil might create only a temporary salinity problem that would naturally correct itself. This approach could also

Table 3

PRODUCTIVITY RATINGS FOR A SOIL AT A POTENTIAL LAND APPLICATION SITE

Property	Value	Rating
Reaction (pH)	6.0 (4.6-6.9)	Fair
Salinity (E.C.)	1	Good
Sodicity (SAR)	1	Good
Saturation %	30 (Est.)	Fair
Texture	LS	Poor
$CaCO_3$ % Equivalent	0	Good

be easily tested in field trials. The consequence of this approach, however, is that one would expect some groundwater contamination. The concentration of the salts reaching the water table would probably be less than in the waste due to dilution with soil water, diffusion of salts and hydrodynamic dispersion. Unfortunately, adsorption or precipitation of the highly mobile chloride salts in the soil profile is unlikely. Dilution of salts at the water table with the groundwater might also lessen the impact of these added salts. This approach might work for a specific situation, but should be very carefully tested and monitored before it is implemented.

A third approach is to reduce the salt content of the drilling waste before land application. Often, the pretreatment of a waste can reduce land application costs considerably (Overcash and Pal, 1979). Reducing the salt content reduces the area of land needed for land application and increases the value of the positive components of the waste to the land. The majority of the salt in the KCl drilling waste resides in the soil solution. Removal of this saline solution could be accomplished through filtration, leaching or washing. The saline fluid would be disposed of by deep well injection and the remaining solids portion would be applied to land.

SUMMARY

The objectives of this paper have been to explain the factors which should be evaluated when considering the land disposal of wastes, and to evaluate a saline drilling waste as to its suitability for land farming. Land disposal has been shown to be an economical and efficient means of dealing with a wide variety of industrial and municipal wastes. A prime consideration for any land disposal scheme is to maintain or improve the quality of soil and groundwater resources.

A significant component of a saline drilling waste is the solids fraction. The suitability of the solid fraction of a waste for land disposal can be evaluated by comparing it to soil and the properties of soil that can determine a soil's productivity. A rate of application of waste to soil can then be calculated which results in the optimum properties for the amended soil.

The evaluation of the saline drilling waste indicates that it could be used to improve soils of low pH and sandy texture. The land limiting components of the waste are considered to be the salinity and sodicity factors. The sodicity hazard could possibly be alleviated through the application of gypsum. Three options to consider in addressing a salinity hazard include spreading small amounts over large acreages, spreading at a rate which creates a short-term, but acceptable, salinity problem, and applying the solid fraction of a waste after removing excess salt through filtering, leaching or washing.

Each waste disposal problem requires unique approaches and solutions. The challenge for all of us is to determine unique ways of disposing or utilizing wastes in environmentally safe manners.

REFERENCES

Alberta Soils in Advisory Committee. 1981. Proposed soil quality criteria in relation to disturbance and reclamation. Alberta Agriculture. 52 p.

Overcash, M.R. and D. Pal. 1979. Design of land treatment systems for industrial wastes - theory and practice. Ann Arbor Science Publishers Inc. 684 p.

RECLAMATION OF OIL AND SALT WATER SPILL SITES

R. Innes[1]

- Title should perhaps be changed to Hydrocarbon and Saltwater Spill Sites.

  i.e. Crude Oil

  Processed Oil

  Treated Oil with Solvents to Reduce Viscosity

  Gasoline

  Diesel Fuel

  Condensate C_{7+}

  Oil and WAter, Water and Oil Emulsions.

  All lead to a different set of site conditions.

- In terms of site ecology, three basic sets of conditions exist.

  1) Agricultural
  2) Forestry
  3) Muskeg

1.0 HYDROCARBON SPILLS

In any surface hydrocarbon spill the initial actions must be the following:

1) Locate and stop source
2) Containment, dykes, straw bales, interseptor trenches
3) Recovery - remove as much product as possible

1.1 AGRICULTURAL LAND - SURFACE

- Initial clean-up followed by volatilization of light ends.

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[1] Soils Consultant, Hardy and Associates, Edmonton, Alberta. (Original paper misplaced and substituted with present material.)

- Burning does not help - leaves a surface crust of non-combustable material.
- From this point on, reclamation is a microbial process "BIODEGRADATION" HYDROCARBON -CO_2 and H_2O.
- For this to work you must optimize microbial activity.

1) Decomposition is an aerobic process (requires oxygen). Not the same rate for all, i.e. fats and waxes biodegrade very slowly.
2) No need to innoculate with microbes, they are already there.
3) Require aeration - i.e. tillage, addition of fibre, increase pore space.
4) Hydrocarbons alter the physical properties of a soil, i.e. they reduce soil wettability. Plants and micro-organisms obtain their nutrients from soil water. Must improve soil wettability.
5) Not able to give a blanket approach to how much hydrocarbons enter soil or how deep it penetrates. This depends on:
    - soil type
    - type of hydrocarbon
    - ground cover
    - topography and hydrogeology

   Time requirements will vary related to the same factors.
6) In general: for biodegradation to occur.
    - alter drainage conditions if too wet or irrigate to optimize moisture
    - maintain a near neutral pH - liming. $CaCO_3$ not CaO.
    - assure an adequate supply of nutrients
      N:P:K applied at 100:10:1 (required 10:4:10 but soil conditions specify). Nitrogen most important - do not apply too much as it will be toxic to plants.
    - check for Na - many oils contain brine
7) Requires monitoring monthly ---
    - determine N:P:K and apply nutrients to maintain
    - determine total hydrocarbons to measure effectiveness
    - observe return of hydrocarbons to surface - water table

8) Seed
   - almost any applicable crop; oats and wheat not as sensitive
   - a variety of grass seed mixtures available

1.2 VADOSE ZONE - UNSATURATED

Stanley Associates currently working on a project in this regard related to decommissioning - nutrient and oxygen injection.
Related to hydrocarbons retained in subsurface with a potential for groundwater contamination.

1.3 FORESTED SOILS - ADEQUATE DRAINAGE

- Most reclamation problems are caused by poor or ineffective clean-up.
- Reclamation must never be considered an alternative to clean-up. Initial steps are most critical
  1) stoppage of flow
  2) containment - in drained forested conditions very important as it will affect surface water
  3) recovery of free product
  4) assessment of site conditions
- In forested condition bear in mind the essential problem is the presence of oil not the absence of plants.
- In the past have used burning.
  - dangerous
  - leaves tarry crust of non-combustible
  - creates loss of soil nutrient availability
- In the past have used removal.
  - creates erosion problems
  - vegetation difficult after removal of topsoil
- Avoid the above, if plants die leave the root stocks in place.
- Trees are not very tolerant to hydrocarbon spill conditions and addition of nutrients during reclamation may make it worse.
- As is the case of agricultural land
  1) remove tree vegetation - leave roots

2) tillage to improve aeration

3) addition of fibre to improve wettability and reduce erosion

4) adjust and maintain pH

5) add and monitor nutrient additions

6) see to grass and/or transplanted plugs

    Oats
    Reed Canary Grass
    Stream Bank Wheat Grass
    Alsike Clover
    Brome Grass

- September and October are best time to initiate seeding to get a good start in spring (agricultural land any time).

1.4 MUSKEG

- Basically three types: Bogs, Fens and Marshes.
- In agricultural and forested land wettability was identified as a major problem.
  The opposite is the case here.
- After volatilization a crust forms on the surface which reduces evaporation and maintains saturation.
- In addition the pore space is full of water and hydrocarbons (anaerobic). Minimal oxygen for biodegradation.
- The temperature in muskeg is lower, i.e. reaction rate temperature dependent - also shorter growing season.
- different soil chemistry
  - often acidic
  - saline
  - nutrient deficient
- limited accessability for men and equipment

After a spill

Containment

dykes
wiers and culverts
trenches

Clean-up

flushing
skimming
sorbents
stripping
burning

Associated Storage and Disposal Problems

Reclamation

1) application of nutrients (N:P:K:S)
2) addition of lime to reduce acidity and stimulate growth
3) tillage if possible to break up surface crust; promote aeration and seed germination
4) improve drainage of the muskeg
5) reseed or replant with transplanted plugs

2.0 SALT WATER SPILLS

- The major problem associated with salt water spills is not the initial toxicity of chloride as it is readily mobile through soil.
- The problem associated with reclamation of brine spill sites is the effect of sodium on clay minerals, i.e montmorillonite. Sodium disperses the clay and creates a zone of low permeability.
- The key factor here is the Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na}{\frac{Ca+Mg}{2}}$$

As the SAR increases productivity decreases. When SAR is in the range of 15 the soil is non-productive.

- This sodium is affixed to the clay so it will not be leached out, i.e. it must be replaced by another cation.

2.1 AGRICULTURAL LAND

- Initial steps are to:
  - stop the source
  - containment

  - recovery
  - disposal
- Determine size of spill affected area - in three dimensions. Use geophysical technique of Induced Electrical Conductivity or drilling and sampling on a grid.
- In the case of agricultural land assume relatively flat and have absorbed the majority of the fluid.
- Obtain soil samples to a minimum depth of one metre in spill affected area and background.
- Analysis for

  Sodium
  Calcium
  Magnesium
  Potassium
  Chloride
  Sulphate
  Electrical Conductivity
  pH

  and calculate SAR.
- Based on this data determine the quantity of calcium required to replace sodium.
- Apply gypsum ($CaSO_4 \cdot 2H_2O$) on surface and till to a maximum depth of 30 cm, or
- Apply SSC 50 (trade name for Calcium Nitrate) - Use caution or you will create a nitrate toxicity problem.
- Determine nutrient status as they will have been leached out.
- Apply nutrients required in conjunction with seeding (crop or grass seed mixtures).
- Monitor by soil sampling and analysis (period of one to five years required).

2.2 FORESTED LAND

Follow procedure identified in Diagram 1, CPA Reclamation of Brine Spills in Upland Boreal Forest Areas.

2.3 MUSKEG

- Reclamation measures may be long-term, costly and may not be effective.

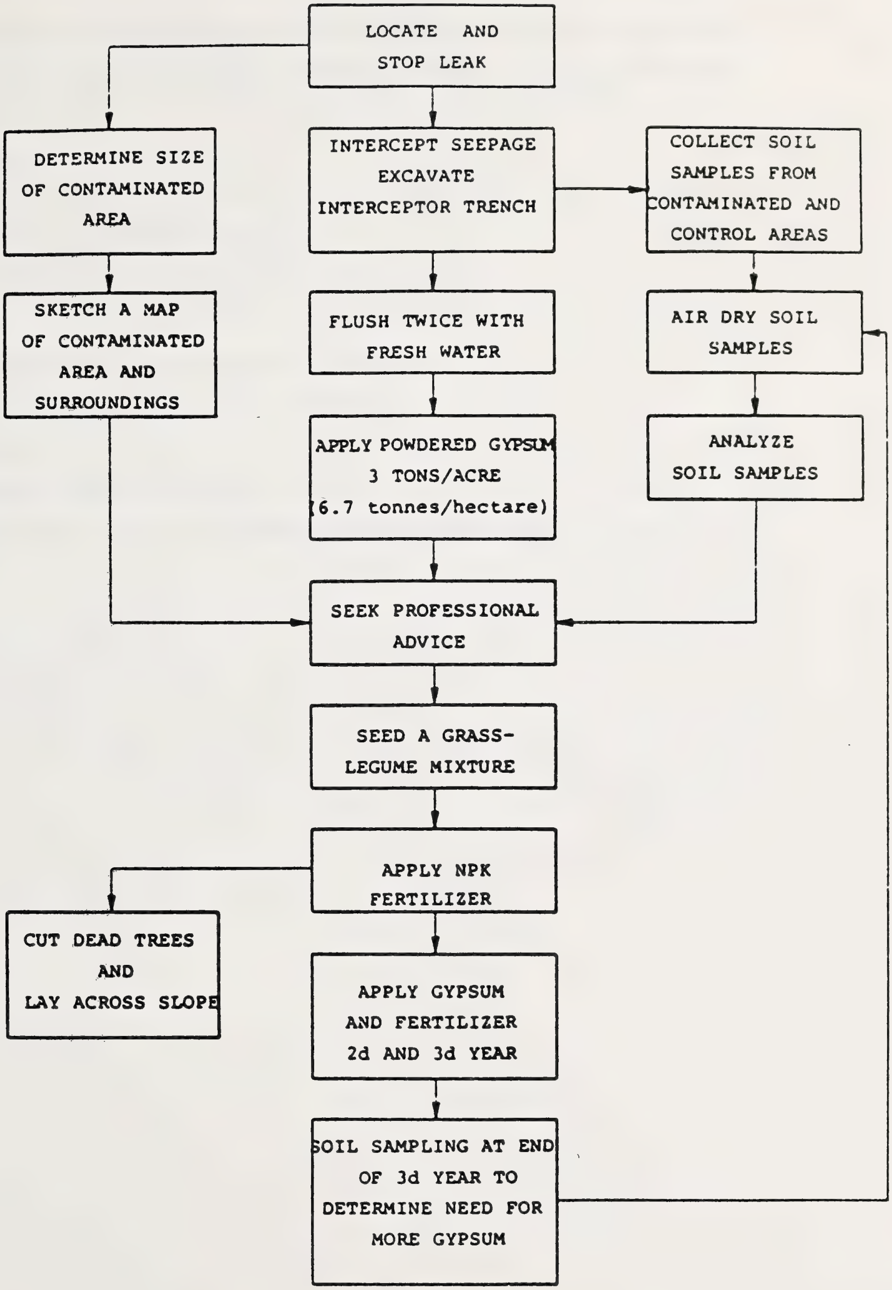
LOCATE AND STOP LEAK
DETERMINE SIZE OF CONTAMINATED AREA
INTERCEPT SEEPAGE EXCAVATE INTERCEPTOR TRENCH
COLLECT SOIL SAMPLES FROM CONTAMINATED AND CONTROL AREAS
SKETCH A MAP OF CONTAMINATED AREA AND SURROUNDINGS
FLUSH TWICE WITH FRESH WATER
AIR DRY SOIL SAMPLES
APPLY POWDERED GYPSUM 3 TONS/ACRE (6.7 tonnes/hectare)
ANALYZE SOIL SAMPLES
SEEK PROFESSIONAL ADVICE
SEED A GRASS-LEGUME MIXTURE
APPLY NPK FERTILIZER
CUT DEAD TREES AND LAY ACROSS SLOPE
APPLY GYPSUM AND FERTILIZER 2d AND 3d YEAR
SOIL SAMPLING AT END OF 3d YEAR TO DETERMINE NEED FOR MORE GYPSUM

DIAGRAM 1 FLOW CHART OF OPERATIONS FOR RECLAMATION OF BRINE SPILLS IN UPLAND FORESTED AREAS

- Key elements are containment and recovery. Determine three dimensional size of spill affected area. Use geophysical techniques.

  Containment

  1) Dykes
  2) Trenches and Bell Holes
  3) Establish a flow direction and gradient

  Recovery

  1) Pumping from Bell Holes or Trenches
  2) Pumping with associated flushing

  Reclamation

  1) Upgrade nutrient status
  2) Allow for natural regeneration or transplanted plugs

SOME DEGRADATIVE CAPABILITIES OF SOIL MICROBES, WITH REFERENCE TO DRILLING WASTE ORGANIC ADDITIVES

J. Foght[1]

ABSTRACT

Soil microbes are essential biological components of the soil. Their degradative capabilities are varied, and include both natural and xenobiotic compounds. Degradation of these compounds in soil is influenced by three main factors: physical and chemical environmental parameters; the nature of the compound; and the microbial population. Recent scientific literature regarding the degradation of some specific drilling mud organic additives is discussed. A synthesis of these results allows extrapolations for potential disposal alternatives for drilling muds.

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INTRODUCTION

Microbes are essential in degradative processes and in nutrient cycling in soil. Because the ultimate receptacle for drilling mud wastes is the soil (whether via subsurface or surface disposal), an understanding of the nature of soil microbes is necessary. In addition, the degradative capabilities of soil microbes with respect to the organic additives in drilling muds should be evaluated.

Soil microbes, that is, bacteria and fungi, are ubiquitous in global distribution, being found in locations as diverse as hydrothermal vents at the sea bottom and in Arctic snows. In soils, their vertical distribution usually parallels the organic content of the soil profile. That is, the majority of the microbial population is found in topsoil with numbers and diversity generally decreasing with depth. The absolute numbers and the population diversity will depend on a variety of factors, as will the ultimate degradative capabilities of the population.

The concept of "microbial infallability" proposes that, for every naturally occurring organic compound, there is a microbe or a consortium of microbes capable of its degradation. With the introduction of synthetic compounds, or "xenobiotics" into the environment, this concept has been sorely tried and there are examples of anthropogenic organic compounds which are degraded extremely slowly, if at all, leading to environmental persistence. This recalcitrance to degradation and the resultant potential for environmental accumulation is obviously undesirable, especially if the compound is toxic.

This paper will attempt to provide a brief overview of some microbial degradative capabilities in the soil. Although very little research has been reported in the scientific literature, this paper will make reference to the degradation of some specific organic compounds used as additives in drilling muds.

GENERAL DEGRADATIVE CAPABILITIES OF SOIL MICROBES

Under favorable environmental conditions, soil microbes are capable of degrading a wide variety of organic compounds. That is, compounds containing carbon, hydrogen, oxygen, phosphorus, sulfur, etc., can be broken down into simpler components via microbial enzymes. The constituent elements may then be used to make cell material, to generate metabolic energy or for a combination of both processes.

Simple compounds like sugars (e.g., glucose) and amino acids are readily utilized by many organisms, being building blocks for larger cell constituents. Similarly, more complex organic compounds and "homogeneous polymers" such as cellulose and protein composed of simple repeating units (e.g., glucose and amino acids, respectively) are also readily utilized.

The decomposition of large, complex organic molecules and "heterogeneous polymers" (e.g., humic acids, lignins) proceeds at a much slower rate, since the increased diversity of functional groups and chemical bonds makes degradation more difficult. Consortia or microbes may be involved in the breakdown of these complex molecules, as in the degradation of mixtures of compounds (e.g., diesel fuel). In petroleum, for example, the range of compound classes (e.g., linear aliphatics, alicyclics, aromatics, hetercyclics, asphaltenics, etc.) demands a variety of degradative strategies exceeding the capabilities of a single microbial species.

Generally, the simpler, readily used compounds in soil will quickly be assimilated by the microbial population and the more complex, recalcitrant molecules will be attacked only after the simpler compounds are exhausted.

MECHANISMS OF DEGRADATION

The presence of simple utilizable compounds or monomers usually induces the production of appropriate enzymes in the soil microflora. These small compounds are then transported into the cells for further enzymatic modification or for direct incorporation into cell constituents. In contrast, complex compounds and polymers are often much too large to be transported directly into the cell and therefore must be depolymerized or partially degraded outside the cell (Demain, 1984) with subsequent transport of the breakdown products. To effect this external decomposition, the compound must be able to induce the production of certain "extracellular" (that is, exported) enzymes and corresponding intracellular enzymes for utilization of the degradation products. Heterogeneous polymers or complex compounds may not be able to induce this enzymatic activity and therefore will be slow to degrade. If the appropriate enzymes are induced, the polymer may not be completely degraded; rather, side chains and functional groups may be cleaved without extensive alteration of the backbone or of the bulk of the compound. Therefore, degradation of complex, heterogeneous compounds may require a concerted attack by a variety of organisms producing a battery of enzymes. The efficiency of this "degradation by committee" is subject to a host of environmental influences.

PRODUCTS OF DEGRADATION

Under ideal conditions the products of complete, aerobic attack, whether by fungi or bacteria, are CO_2, H_2O and cell mass. Anaerobic attack, which is carried out almost solely by bacteria, can result even under ideal conditions in a wider range of products, including CO_2, H_2O, cell mass, low molecular weight organic acids, gases such as methane, and partially degraded byproducts.

FACTORS AFFECTING BIODEGRADATION

1. Environmental Parameters

As must be evident, the presence of oxygen is a significant factor affecting microbial degradation. Under aerobic conditions, both bacterial and fungal populations are functional; under anaerobic conditions the vast majority of degradative attack is bacterial, since amlost all fungi are aerobes. As previously discussed, the aeration status of the soil will determine in part the products of microbial attack. In general, aerobic attack is a much more efficient, faster and "cleaner" process than anaerobic attack (not to malign the essential anaerobic processes of sewage treatment, industrial fermentations, ruminant digestion, etc.). Aerobic conditions generally are preferred for degradation of xenobiotics and complex compounds, since some compounds are not known to degrade anaerobically (e.g., some hydrocarbons, lignin; Hungate, 1982). The moisture regime of the soil is related to the oxygen content, since waterlogging of soils results in anaerobic conditions. Insufficient moisture, on the other hand, reduces microbial activity.

The soil pH also affects biodegradation. A neutral to slightly alkaline pH (6.5 to 8.0) favors bacterial growth while more acid conditions (below pH 5.5) allow fungi to predominate. Since bacteria as a whole have more degradative versatility than fungi, especially regarding xenobiotics, neutral conditions are preferred.

The presence of organic and inorganic nutrients affects biodegradation. If the compound in question can be used as a carbon source by microbes, the concentrations of nitrogen, phosphorus, potassium and sulfur may be rate-limiting components. Bacteria have an optimum ratio of C:N:P which is upset by an influx of C-rich organic material, and restoration of this balance (ideally about 10:1:0.5 for C:N:P) by the addition of organic or inorganic N and P fertilizers may enhance biodegradation. Sorption of these nutrients or the organic compound itself to clays may restrict degradation by reducing availability.

The presence of inorganic salts (e.g., $NaCl$, KCl, $CaSO_4$, etc.) can reduce both aerobic (Bourquin, 1984) and anaerobic (McCarty, 1964) biodegradation since only a fraction of the soil population is salt tolerant. Also, the dispersive effects of some monovalent cations or clays may lead to unfavorable aeration, moisture and sorptive conditions (see other papers, this publication), thus indirectly affecting biodegradation.

The season of the year also affects biodegradation through two additional parameters: temperature and photoperiod. Biodegradation in soils is usually optimal between 10°C and 30°C with very little activity below 0°C. Ultraviolet radiation can cause photolysis of certain compounds, rendering the molecules more susceptible to microbial attack.

The combination of all these factors would suggest that degradation is favored in a well aerated, neutral, fertile soil during summer months.

2. Chemical Composition

The chemical nature of the compound determines to some extent its biodegradability. For example, the size of the compound affects its water solubility which in turn influences its availability (soluble forms of polymers are more susceptible to microbial attack than insoluble forms). As well, the absolute number and variety of chemical bonds encountered in large, complex compounds affects ease of degradation. The presense of condensed aromatic rings usually promotes recalcitrance, as does an increasing degree of halogen substitution. For example, biphenyl is degradable, but polychlorinated biphenyls (PCB's) are recalcitrant (Catterjee and Chakrabarty, 1981). Certain functional groups can affect biodegradation, also. For example, the introduction of an oxygen atom into aromatic nuclei can enhance anaerobic degradation (e.g., phenol versus benzene).

The presence of other compounds can inhibit biodegradation. For example, di-2-ethylhexyl-phthalate (DEHP) alone is susceptible to microbial degradation, but becomes resistant when incorporated into PVC films (Bourquin, 1984). As previously noted, the presence of an energetically favorable substrate will delay degradation of a recalcitrant compound. Alternatively, combinations of chemicals may prove toxic to microbes.

An unanswered question relates to the potential for _in situ_ alteration of drilling mud additives at high pressure and temperature. Thermochemical alterations could render compounds more resistant to degradation via condensation/polymerization reactions, through chlorination reactions in salt muds, or could make the compound more susceptible to biodegradation through decomposition and/or oxidation.

3. Microbes

The third major factor influencing biodegradation is obviously the microbes. Bacteria as a group have a greater xenobiotic degradative capability than fungi and have the added advantage of possessing species which can grow aerobically, anaerobically or under either condition. The fungi, on the other hand, are usually restricted to aerated soils. The absolute number of microbes in a population helps determine the rate of degradation ("normal" population densities may exceed one million to one million per cubic centimetre of soil), but the proportion of bacteria and fungi will also affect the biodegradation potential. Obviously, with increasing depth in a soil profile, the absolute number of microbes decreases and the proportion of anaerobes increases, generally leading to a depressed degradative capability.

Fortunately, the microbial population is very flexible and can display an adaptive response to the influx of certain compounds. If the compound is utilizable, those organisms specificallay able to use it may gain a competitive advantage over other microbes and thus multiply at a faster rate. This tends to enrich the population for specific degradative microbes, and this enrichment by prior exposure is exploited in oily sludge landfarming operations.

A concern that should not be overlooked is that the enrichment of specific components of the soil microflora can theoretically result in the production of toxic byproducts (e.g., fungal toxins) or enhanced numbers of human and/or plant pathogens (e.g., _Clostridium_, _Fusarium_).

Therefore, it can be seen that the degradation of organic compounds in the soil is influenced by a large array of factors which may also interact competitively or synergistically. This makes predictions regarding degradability of compounds difficult.

DEGRADATION OF SPECIFIC DRILLING MUD ADDITIVES

Only certain organic additives are considered here; bacteria have no degradative effect on the inorganic salt and clay components of drilling muds.

1. Xanthan Gums

Xanthan gums may be added to drilling muds as a viscosifier (see other papers, this publication). The gums have a cellulosic backbone with saccharide sidechains; the backbone makes the polysaccharide somewhat sensitive to cellulases. However, true degraders of the polymer appear to be uncommon in soil and it is proposed that multiple enzymes are required to effect complete degradation of xanthans (Slodki and Cadmus, 1983). The use of mixed rather than pure cultures has been shown to enhance xanthan degradation _in vitro_, however, xanthan gums are apparently persistent in soil and side chain cleavage is a more common occurrence than complete degradation.

2. Polyacrylamides

Polyacrylamide is also used as a viscosifier and appears to be resistant to microbial degradation in soil. Its presence is capable of stimulating the growth of certain aerobes, possibly by serving as a nitrogen source through spontaneous chemical release of ammonium ion. It can also stimulate growth of and sulfide production by certain sulfate reducing bacteria under certain conditions. No extracellular enzymes for degradation of polyacrylamides are known (Grula and Sewell, 1983).

3. Celluloses, Starches and Lignosulfonates

Cellulose and starch are polymers composed of the same monomer, glucose, linked in a different manner. Their relative solubilities dictate that starch is easier to degrade than cellulose. However, cellulose is readily degradable by microbes (and fungi in particular) under aerobic conditions, being degraded more slowly under anaerobic conditions.

The lignosulfonates, used as thinning agents, tend to be much more recalcitrant than their parent lignin compounds (Kern, 1981), which themselves are persistent.

4. Diesel Fuel

Diesel fuel may be added to drilling muds as a lubricant. Many of its components are readily degradable by bacteria under aerobic conditions, while being persistent under anaerobic conditions. Some of its low molecular weight components (e.g., benzene, pentane, etc.) may be toxic to microbes.

EXTRAPOLATIONS

Only a few specific drilling mud additives have been addressed in this paper because the degradation of many of the organic additives has not been adequately studied. The additional complication of in situ alteration of these additives down hole has not been examined in the literature; nor has the effect of combinations of organic additives and/or inorganic drilling mud components. For example, what is the effect of the addition of sorptive clays on biodegradation of organic additives? What levels of salt are inhibitory to degradation of specific additives?

It is possible that pretreatment of organic additives before disposal could aid in subsequent microbial degradation by reducing the size of polymers. This enhanced degradation has been demonstrated by pyrolysis of polyethylenes and photolysis of polybutenes to 500 molecular weight (Atlas and Bartha, 1981).

It would appear that certain additives are not readily degradable under either aerobic or anaerobic conditions - for example, polyacrylamides, lignosulfonates, xanthan gums, asphalts. However, some "natural" compounds like celluloses, starches, alcohols and diesel fuels are degradable, especially under aerobic conditions. There is a need for further research on the decomposition of recalcitrant organic additives and on their products of biodegradation.

This conference has raised many questions, one of which is "Has the disposal of organic additives with drilling muds an environmental significance?" If the potential environmental accumulation of the organic additives in drilling muds is a concern, the use of aerobic landfarming (surface disposal) for drilling wastes should be considered and researched as a potential to anaerobic (subsurface) disposal. The use of an aerobic system increases the likelihood of microbial modification of the compounds; use of repeated applications has the potential for developing an adapted, enriched population capable of degrading recalcitrant compounds; some environmental conditions can be selectively altered (e.g., aeration, moisture, pH, fertilization) to enhance degradation; polymers may be exposed to ultraviolet photolysis and photooxidation; and application rates can be controlled and optimized. This landfarming proposal of course is tempered by the physical and chemical constraints imposed by high salt drilling muds (see other papers, this publication).

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SALT EFFECTS ON VEGETATION

I.K. Edwards[1]

ABSTRACT

The effects of salinity on vegetation are manifested primarily as osmotic effects indicated by water stress and secondarily as specific ion effects expressed by nutrient imbalance. The cations, calcium, magnesium, sodium and potassium may replace each other on the soil exchange complex but calcium and magnesium are most important in this regard. Sodium is objectionable because of its harmful effect on soil. Among the anions, chloride is least desirable because of its ease of accumulation and lethal effects although critical concentration varies among plant species. A tentative categorization of trees, shrubs, grasses and forage on the basis of salt tolerance is given. Salt composition is as important a factor as salt concentration in the management of saline drilling wastes.

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INTRODUCTION

The effects of salt (salinity) on vegetation are firstly biochemical disturbance on a cellular level and this change is expressed as a physiological imbalance. The effects may be subtle or highly visible and although they are sometimes reversible, physiological changes may be sufficient to damage plant tissue irreversibly and cause death. In the context of wastes resulting from the use of drilling muds in Alberta, salinity is high with the salt consisting of sodium and potassium chlorides, predominantly. Smaller amounts of magnesium chloride, sodium sulphate, and potassium sulphate are also present. Spills or "blow-outs" at well sites and elsewhere contaminate soils with these salts and the environmental implications are obvious. The objective of this review is to outline the basic biochemical principles and physiological concepts that come into play when plants interact with excessive salinity in their environment and describe the plant physiological results of salt stress from quantity (osmotic effects) as well as quality (specific ion effects).

BASIC CONCEPTS

Biochemical Principles

On a cellular level, movement or diffusion of substances across a membrane will be governed by permeability of the membrane and the driving force causing the diffusion. The driving force or free energy of any substance is the amount of energy it has available for doing work. The greater its free energy, the greater will be the tendency for it to take part in chemical reactions (chemical potential) and other processes such as diffusion.

Movement across a membrane may be active or passive. If chemical potential (CP) is higher outside the membrane, e.g., cell wall, movement will be towards the inside. This is passive movement and is dictated by the fact that free energy or chemical potential moves down a chemical potential gradient, i.e. from high CP to low CP. In active diffusion, movement is against a CP gradient; energy is provided by the cell to accumulate substances although CP is higher inside.

When a membrane containing a salt solution is surrounded by water, water moves through the membrane into the salt solution. Chemical potential of the water in the salt solution has been reduced by the ions supplied by the dissolved salt. The degree by which chemical potential of water in a salt solution is reduced is equivalent to the osmotic potential (OP) of the solution. Osmotic potential (or osmotic pressure with a negative sign) is due to the presence of solute particles and increases as salt concentration increases. Therefore, if a cell is surrounded by a salt solution of higher concentration than that inside, the higher osmotic pressure of the outside solution will cause water to move outwards from the cell.

Movement of cations and anions across a cell membrane, occur at different rates because of their positive and negative charge, respectively, and an electrical potential is created across the membrane. If electrical potential is negative, cations are transported passively whereas anions are moved actively. Overall, electrical neutrality is maintained however because if uptake of cations exceeds anions, hydrogen ions (H+) are exchanged. Similarly, if uptake of anions exceeds cations, hydroxyl (OH^-) and bicarbonate (HCO_3^-) ions are moved out of the cell. Intrinsic permeability of cells of different species also accounts for the differential rate of accumulation of ions. Differential accumulation imparts to the species characteristic osmotic potential for cell sap (Table 1).

OSMOTIC EFFECTS

As the level of salinity increases in soil, osmotic potential of the soil solution increases. Water will move toward it because of the low chemical potential of the solution. The osmotic potential is a measure of how strongly the soil holds on to its water and if sufficiently strong, plants will have difficulty in taking up moisture. The effect of salt is primarily to reduce absorption of water and although the effect varies with species, as salinity increases, growth is reduced. In extreme cases, high osmotic potential of the soil solution causes movement of water away from plant roots in the saline environment. As growth is restricted, the concentration of

Table 1

CHARACTERISTIC OSMOTIC POTENTIAL OF CELL SAP OF SELECTED PLANT SPECIES

Plant Species	**OP (- atmospheres)**
Atriplex (*A. confortifolia*)	24-202
Sagebrush (*Artemisia tridentata*)	14- 73
Colorado spruce (*Picea pungens*)	51
Willow (*Salix* spp.)	35
Cottonwood (*Populus deltoides*)	21
Dandelion (*Taraxacum officinale*)	14
Chickweed (*Stellaria media*)	7

some elements increases, and a wider imbalance in nutrients can be tolerated.

A commonly used measure of soil salinity (or salt concentration) is electrical conductivity. Osmotic potential is directly related to electrical conductivity but the latter is more easily determined. For equivalent concentration, salts of chloride will give higher conductivity (and osmotic potential) values than those of sulphate or bicarbonate. Plants have been categorized on the basis of their sensitivity to soil salinity as measured by restriction in crop growth. The rating, applicable primarily to agricultural and horticultural crops, is as follows:

EC reading mS/cm	Category
0 - 2	Salinity effects mostly negligible
2 - 4	Yield of very sensitive crops may be restricted
4 - 8	Yield of many crops restricted
8 - 16	Only tolerant crops yield satisfactorily
greater than 16	Only few tolerant crops yield satisfactorily

There is evidence that forest species are not as tolerant of salinity as most agricultural crops. In tree nurseries in the prairie provinces, salinity levels of less than 2 mS/cm will suppress the growth of conifer seedlings. Deciduous species are reported to be more tolerant of soil salinity.

Water Stress

Water stress within the plant is the most prominent effect of a highly saline environment. As uptake of water is reduced (owing to high osmotic potential of the soil solution) and growth rate declines, transpiration increases, thus compounding the effect of the stress. The symptoms of salt damage, namely magenta colored needles, tip burn, marginal scorch, die-back, cupping of leaves, leaf fall and necrosis, are the first to develop. Plants become stunted and may appear deep green or deep blue-green. (The bluish appearance is due to a heavy waxy coating that is formed; an increase in chlorophyll on an area basis is responsible for the intense green color). Stunting is most pronounced at the terminus of the vascular tissue as protoplasm initially dries out with the onset of water stress. Wilting is often not noticed because of the reduced rate of water absorption.

Germinants and young seedlings are most susceptible to high salinity. Application of fertilizers to an already saline area may correct nutrient imbalance to no avail. It increases osmotic potential of the soil solution and exacerbates an already high water stress. Salt accumulation increases transpiration by impairing stomatal regulation. On a weight/equivalent basis chloride salts inhibit growth more than sulphate.

The potency of chloride ion has serious implications for treatment/handling of saline drilling wastes, especially in arid and semi-arid locations. If plant productivity is low initially because of lack of soil moisture, any increase in salinity will result in a significant increase in osmotic potential of the soil solution and the net effect will be even greater moisture stress and mortality. (The effect has been observed at a "blow-out" site on range land near Medicine Hat, Alberta.) Similarily, plants that may be only slightly affected by salinity in cool weather, will be more likely to produce symptoms during hot weather.

SPECIFIC ION AND SALT EFFECTS

The effects of osmotic potential (salt effect) are differentiated from specific ion effects by observing the concentration at which various salts suppress growth. If different salts at similar osmotic potential cause similar reduction in growth, they have a similar osmotic effect, e.g., Na_2SO_4 and $CaCl_2$. If the deviation in response varies with the salt, there is a specific ion effect, e.g., $MgCl_2$ and $MgSO_4$. Both of the latter suppress growth far more than the former at similar osmotic potential. Sodium chloride is 5-10 times more toxic than $CaCl_2$. Corn growth was better with $CaCl_2$ than with either NaCl, $MgCl_2$, or KCl at comparable osmotic potential. Chloride reduced translocation of carbohydrate and reduced growth compared to sulphate. Nitrogen assimilation, however, has modified the effects of NaCl and $CaCl_2$ on bean. Chloride (up to 3 000 ppm) had no effect on uptake of nitrate or phosphate but both anions decrease uptake of Cl.

Nutrient Imbalance

High Na *per se* has little effect on nutrient balance within the plant but on the soil exchange complex it replaces Ca and Mg and causes deterioration of soil structure. A high level of Ca in the soil will depress plant uptake of K and Mg; high K will depress uptake of Ca and Mg, and high Mg will depress uptake of Ca and K. Sodium had no effect on uptake of K but K reduced uptake of Na. A combination of Ca and Na will reduce uptake of K especially in plants that normally tend to accumulate less K. Sulphate suppresses absorption of Ca but promotes uptake of Na.

Cations more readily replace each other with regard to plant uptake. The effects are more striking on sand than on clay because of the buffering capacity of the latter. Anions generally are more stable and it has been postulated that stability is due to the presence of specific absorption sites and that anions are rapidly converted into organic compounds.

ION TOXICITY

Toxicity is salt injury that cannot be accounted for on the basis of osmotic potential. It is inhibition in growth or function due to excess accumulation of a specific ion. It is difficult to distinguish between specific ion effects and toxicity because both are closely linked. Excess Mg, for example, will depress uptake of Ca and K to the extent that the plant may develop either Mg toxicity or deficiencies of Ca and K, or both.

In the context of management of saline drilling wastes in Alberta, Cl toxicity specifically is a major concern. The mechanism of Cl toxicity remains unknown. Following uptake, it is translocated easily (high mobility) to the extremities of the plant, e.g., meristematic tissue and foliage. Tip burn, marginal scorch and dieback are common toxicity symptoms among plants. Many conifers, e.g., colorado spruce, white spruce, black spruce and balsam fir, develop chlorosis initially, become pink and finally develop a reddish brown (magenta) tint of the needles beginning at the tip and progressing towards the base. Also, the current year's needles are affected initially.

Investigations in Alberta involving lodgepole pine, Colorado spruce and black spruce have indicated that normal Cl levels are 200-500 ppm and Cl toxicity symptoms begin to appear at Cl levels of 800-1 500 ppm. In black spruce, death occurred at 4 000-7 000 ppm whereas in Colorado spruce, lethal Cl levels were 2 000-3 000 ppm.

Deciduous species have a higher tolerance for Cl. Symptoms of Cl toxicity in American elm and sugar maple appeared above 3 000 ppm. In Alberta (Swan Hills), paper birch first indicated toxicity symptoms (foliar discoloration) at 9 000 ppm and mortality occurred at 30 000 ppm. However a Saskatchewan study of the effect of Cl-laden emissions on surrounding vegetation indicated critical Cl levels of 1 000-1 200 ppm for conifers and 800-1 600 ppm for deciduous species. Annual "flushing" through leaf fall may play a role in long term tolerance of deciduous species to salinity. Plants may resist salinity damage by means of either tolerance or avoidance. Avoidance may take the form of exclusion, extrusion, and dilution of the entering salt but the capability varies with plant species. Vegetational responses to high salinity are also affected by climate (moisture, temperature), soil (fertility, background salinity level), and nutritional status of the plant. Widely diverse species have similar critical Cl levels and this suggests a common mechanism or condition through which plant tissue is damaged.

TOLERANCE TO SALINITY

It is difficult to categorize plants on the basis of tolerance to salinity because test results have been taken from different sources and obtained under widely different conditions. If the critical levels at which toxicity symptoms (including suppression of growth) appear are arbitrarily set at less than 1 500 ppm for "Low", 1 500-3 000 ppm for "Moderate", and above 3 000 ppm for "High", many crops can be separated into broad tolerance categories. In the interest of local management of saline drilling wastes and implications for reclamation, a number of coniferous and broadleaf species, shrubs, grasses, and forage crops are categorized tentatively for salt tolerance.

Coniferous Species

L	M	H
Red pine	Tamarack	Jack pine
Scots pine	Norway spruce	Mugo pine
White pine	Juniper	Black spruce
Colorado spruce	White cedar	
Balsam fir		

Deciduous Species

L	M	H
Manitoba maple	Birch spp.	Mountain ash
	Aspen	American elm
	Bur oak	Willow

Shrubs

L	M	H
Hawthorn	Alder	Russian olive
Dogwood	Buckthorn	Honeysuckle
Spirea	Forsythia	Lilac
		Caragana
		Chokecherry
		Mayday

Grasses/Forage

L	M	H
Timothy	Perennial ryegrass	Western wheatgrass
Meadow foxtail	Bromegrass	Canadian wild rye
Alsike clover	Tall fescue	Bermuda grass
Sweet clover	Reed canary grass	Salt grass
	Alfalfa	

SUMMARY

Salinity is devastating to vegetation via i) osmotic effects expressed primarily as low moisture stress and ii) specific ion effects as shown by nutrient imbalances that develop. Excessive accumulation of salts results in toxicity at critical levels. Among cations, Na is least desirable mostly because of its deleterious effect on soil structure. The cations can replace each other on the soil exchange complex. Anions are not replaced as easily and Cl, because of its high mobility, is least desirable. Within the drilling environment toxicity from soluble salt is generally immediate and irreversible and proper handling of salinized wastes is essential.

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DRILLING FLUID SYSTEM SELECTION

D.M. Thomson[1]

There isn't any point in my discussing the various functions of a drilling fluid system, or discussing the various types of systems used, as this has been or will be presented by other speakers at this workshop. Esso's basic approach is to use as simple a drilling fluid system as possible, consistent with being able to drill any given well safely (considers the environment) and effectively at the least possible cost. I would say that this is the normal industry approach, too.

Over the 14-month period ending 85 02 28, Esso had drilled 672 wells in Alberta -- this excludes 107 cored evaluation holes in the Fort McMurray area. Of the 672 wells, 531 were drilled in the Cold Lake area. Of the 672 wells, 667 were drilled with fresh water gel-chemical drilling fluid systems. The other five wells were drilled through salt zones in the Cold Lake area, and saturated salt drilling fluid systems were used to drill through the salt zones to minimize hold enlargement.

The 667 wells were drilled with rather simple fresh water gel-chemical drilling fluid systems with as much hole as practical drilled with water. There were some additives used other than bentonite such as the following:

- soda ash to reduce calcium ion concentrations
- caustic soda for pH adjustment
- lime to flocculate bentonite to increase funnel viscosity and yield point when drilling through gravel and boulders
- calcium chloride, lime and flocculant when drilling with water

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[1] Drilling Engineer, Esso Resources Canada Limited, Calgary, Alberta.

- thinners and water to control viscosity after "mud-up", as the term is used
- extenders to improve bentonite yield
- filtration reduction agent to lower fluid loss when required
- barite to increase drilling fluid density for well control reasons
- lost circulation material primarily sawdust, cellulose materials, fibres and cement
- corrosion inhibitors
- oxygen scavengers
- H_2S scavengers

ENVIRONMENTAL, GEOLOGICAL AND OPERATIONS CONSIDERATIONS WHEN USING SALINE DRILLING FLUIDS - SHELL CANADA'S EXPERIENCE

D.A. Mead[1]

Shell Canada is pleased to be invited to this workshop on Gel and Saline Drilling Wastes. The topic of saline drilling wastes, in particular, is a very timely one and Shell has had considerable experience using these types of drilling muds.

We have chosen to divide our presentation into three sections, and a different person will be handling each part. My title is Staff Ecologist. I work in the Environment Affairs group of Shell Canada Ltd., with primary responsibility for providing environmental expertise to Shell's western exploration and oil sands groups. I will be giving a brief presentation on Shell's environmental policy related to wastes and the corporate responsibility for dealing with wastes. I will also make a few remarks regarding our experience in the effective and safe disposal of saline drilling wastes.

Our second speaker will be Dave Woodland. Dave is a senior research chemist at Shell's Calgary Research Centre. His specialty is drilling muds and he has extensive experience in this area of expertise. Dave will explain some of the rationale behind our decisions to use saline drilling muds (primary KCl), describe some situations where we have used them and present some statistics related to their use.

Our third speaker will be Don Scott. Don is the Superintendent of our Logistics group in Shell's Drilling Division. The Logistics staff are responsible for planning and supervising the construction of access roads, drilling locations and sumps; and also responsible for waste drilling fluid disposal, sump cleanup and restoration of the drilling location. Don has considerable experience in this area, including the cleanup of KCl sumps. Don will relate some of the practical considerations associated with constructing and cleaning up drilling locations and sumps.

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[1] Staff Ecologist, Shell Canada Limited, Calgary, Alberta.

SHELL POLICY - ENVIRONMENT AND WASTE DISPOSAL

Shell Canada, and, indeed, all Shell companies worldwide, takes its environmental responsibilities very seriously. Shell has long had corporate policies in this area, the most recent of which is attached at the end of these comments. Focusing on several elements of the policy is most relevant to this workshop; Shell, as a corporate entity, and Shell employees:

- pay appropriate regard to the environment by acting to protect human, animal and plant life, air, water and soil from adverse effects of its operations
- work with governments, local authorities, industry and others to promote workable, timely and practicable regulations relating to the above matters
- encourage, support and/or conduct research leading to safer and less environmentally damaging technology and operating procedures
- transfer to others the know-how it develops in these fields.

The safe and efficient disposal of wastes generated by Shell activities and facilities is a problem that is addressed on a continuing basis. The policy recently adopted by Shell International Petroleum Company (attached) is wholely supported by Shell Canada. We are proud of our efforts in recent years to seriously and effectively address this issue. Shell was one of the driving forces behind the recently completed Waste Disposal Guidelines prepared by the Canadian Petroleum Association. Using that document as a starting point, Shell prepared its own corporate Waste Disposal Guidelines; one of the first, if not the first in the industry. The sections on drilling wastes are attached to these comments. Shell believes that proper management of its wastes is a part of its business.

ENVIRONMENTAL RESPONSIBIITY

The question can be asked - Who in Shell is responsible for seeing that Shell's policies on environment and waste disposal are adhered to? While all Shell personnel are expected to conduct themselves and their activities in an ethical and environmentally safe manner, the line managers, and most specially the project manager, have the ultimate responsibility. While they rely on environmental, safety and other technical experts for advice in these matters, their responsibility cannot be delegated. The attached diagram gives a pictorial representation of this relationship. The solid line is the line of responsibility leading to senior management and the president of the company. The dotted lines represent input and advice to the managers. The example shows Shell's Health and Environment Department only as an example. There are many other groups with a similar relationship, including the Calgary Research Centre, where Dave Woodland works.

ENVIRONMENTAL IMPLICATIONS OF KCl MUDS

I would like to make a few brief comments on Shell's experience with KCl drilling muds, from the perspective of potential environmental impacts caused by disposal of the saline drilling wastes. There are two potential problems; contamination of soils that will retard or inhibit plant growth and contamination of potable water (both surface and sub-surface) that is used, or may be used, for other purposes. These include water for domestic uses, livestock and irrigation.

Shell has drilled numerous wells in Alberta using KCl muds. In all instances, except the Peace River heavy oil wells, the sump fluids have been dispersed over the lease area or on off-site locations approved by appropriate AENR personnel. The maximum soil loading of 400 kg/ha of chlorides has been adhered to. Saline drilling solids were buried in the sump and capped with clay. All of these disposal sites have been monitored by Shell personnel and AENR staff and no problems have yet been found.

At Shell's Peace River project, a large number of wells are being drilled using KCl muds. We have developed a mud handling system that maximizes the re-use of muds and minimizes the use of fresh water. Our plans for disposal of saline drilling wastes include deep well disposal, following treatment, of all fluids and burial of saline solids. Shell has developed a unique pit system for the handling and disposal of the wastes. The pits are excavated in a deep, clay till deposit. Ultimately, the waste solids will be encapsulated under two metres of compacted clay and four metres above the local water table. Shell has obtained the permission of AENR and Alberta Environment to proceed with this scheme, while closely monitoring the site for migration of salts out of the pit. We confident that our design will work, but also prepared to adjust our methods should problems develop. We should have a good idea of its success by the middle of the summer.

At this point, I will turn Shell's presentation over to Dave. As I mentioned earlier, he will be briefly describing why we use KCl muds, where we use them and our operating experience with them.

MANAGEMENT OF DRILLING WASTES

Policies and Responsibilities	D. Mead
Mud Selection Criteria	D. Woodland
On-site Waste Management	D. Scott

ATTACHMENT 1

SHELL CANADA CORPORATE POLICY ON
- HEALTH
- SAFETY AND
- ENVIRONMENTAL PROTECTION

IT IS THE POLICY OF SHELL CANADA TO CONDUCT ITS ACTIVITIES IN SUCH A WAY THAT THE HEALTH AND SAFETY OF ITS EMPLOYEES AND OF OTHER PERSONS ARE SAFEGUARDED AND PROPER REGARD IS PAID TO THE PROTECTION OF THE ENVIRONMENT. IN IMPLEMENTING THIS POLICY SHELL CANADA COMPLIES WITH THE REQUIREMENTS OF THE RELEVANT LEGISLATION AND ALSO PROMOTES PRACTICABLE MEASURES FOR THE PROTECTION OF HEALTH, SAFETY AND THE ENVIRONMENT FOR ALL WHO MAY BE AFFECTED BY ITS ACTIVITIES.

IN FOLLOWING THIS POLICY SHELL CANADA:

- SEEKS TO AVOID HARM TO THE HEALTH OF, OR INJURY TO EMPLOYEES AND OTHERS AND DAMAGE TO PROPERTY FROM ITS OPERATIONS AND FROM THOSE OF CONTRACTORS ACTING ON ITS BEHALF.
- PROMOTES SAFETY CONSCIOUSNESS IN ITS EMPLOYEES AND CONTRACTORS.
- USES ITS BEST ENDEAVOURS TO PROVIDE PRODUCTS WHICH, WHEN USED FOR THE PURPOSE INTENDED AND IN ACCORDANCE WITH ANY ADVICE PROVIDED WILL NOT CAUSE INJURY OR HARM TO HEALTH OR THE ENVIRONMENT.
- PAYS APPROPRIATE REGARD TO THE ENVIRONMENT BY ACTING TO PROTECT HUMAN, ANIMAL AND PLANT LIFE, AIR, WATER, AND SOIL FROM ADVERSE EFFECTS OF ITS OPERATIONS OR THOSE OF CONTRACTORS ACTING ON ITS BEHALF AND TO MINIMIZE ANY NUISANCE WHICH MAY ARISE FROM SUCH OPERATIONS.
- WORKS WITH GOVERNMENTS, LOCAL AUTHORITIES, INDUSTRY AND ACADEMIC AND PROFESSIONAL BODIES AS APPROPRIATE AND TAKES THE INITIATIVE WHERE NECESSARY TO PROMOTE WORKABLE AND IMPROVED CODES OF PRACTICE, AND TIMELY AND PRACTICABLE REGULATIONS WHICH RELATE TO THE ABOVE MATTERS.
- ENCOURAGES, SUPPORTS OR CONDUCTS RESEARCH DIRECTED TOWARDS THE IMPROVEMENT OF SAFETY AND HEALTH AT WORK, TOWARDS ENSURING THE SAFETY OF ITS PRODUCTS AND TOWARDS THE ABATEMENT OF POLLUTION.
- FACILITATES THE TRANSFER TO OTHERS OF THE KNOW-HOW IT DEVELOPS IN THESE FIELDS.
- KEEPS ITS EMPLOYEES, THE RELEVANT AUTHORITIES AND THE PUBLIC WELL INFORMED ON WHAT IT IS DOING TO PROTECT THE QUALITY AND SAFETY OF THE WORKING AND PUBLIC ENVIRONMENT.
- ANTICIPATES FUTURE REQUIREMENTS AND EXPECTED DEVELOPMENTS IN THESE AREAS IN ITS LONG-TERM PLANNING.
- RECOGNIZES THE IMPORTANCE OF THE INVOLVEMENT AND COMMITMENT OF ITS EMPLOYEES AT ALL LEVELS IN DEVELOPING AND APPLYING THIS POLICY.

THIS CORPORATE POLICY SETS THE GENERAL FRAMEWORK FOR THE DEVELOPMENT AND IMPLEMENTATION OF GUIDELINES TO FULFILL THE NEEDS OF EACH SHELL LOCATION OR SECTOR OF ACTIVITY.

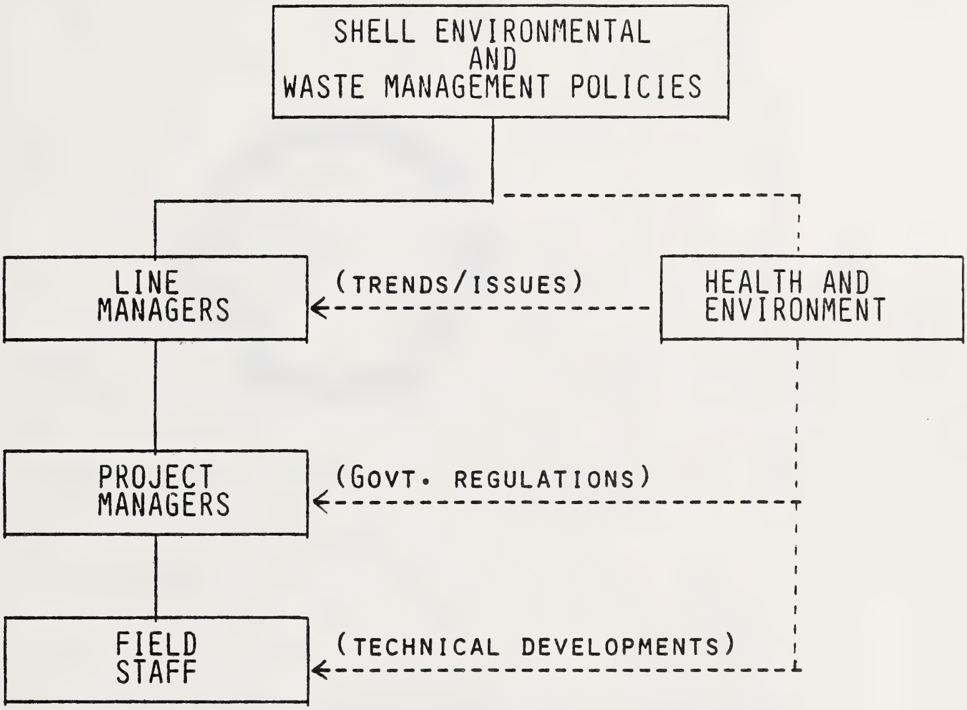
JUNE 1979

WASTE MANAGEMENT

IT IS THE POLICY OF SHELL COMPANIES TO CONDUCT THEIR ACTIVITIES IN SUCH A WAY AS TO TAKE FOREMOST ACCOUNT OF THE HEALTH AND SAFETY OF THEIR EMPLOYEES, AND OF OTHER PERSONS, AND TO GIVE PROPER REGARD TO THE CONSERVATION OF THE ENVIRONMENT. THEY RECOGNIZE THE IMPORTANCE OF SAFE LONG-TERM DISPOSAL OF LIQUID AND SOLID WASTES AND ACTIVELY SEEK OPPORTUNITIES TO EXCHANGE VIEWS ON THE PROBLEMS WITH GOVERNMENTS AND REGULATORY BODIES.

SHELL INTERNATIONAL PETROLEUM COMPANY LIMITED
DECEMBER 1984

ENVIRONMENTAL RESPONSIBILITY



DRILLING FLUIDS

SHELL CANADA RESOURCES LIMITED

SHELL CANADA RESOURCES LTD.
1984 DRILLING FLUID SUMMARY

MUD TYPE / WELL CLASSIFICATION	FRESH WATER MUD	SHELL POLYMER MUD	NaCl/ $CaSo_4$	OIL BASE MUD
PLAINS WELL (61)	57	2	2	0
FOOTHILLS WELLS (12)	5	6	0	1
TOTAL (73)	62	8	2	1
%	85	11	3	1

DRILLING FLUID SELECTION CRITERIA

DRILLING FLUID	SELECTION CRITERIA
OIL BASE MUD	— in areas where the best drilling performance has been achieved historically (eg.) STOLBERG
$NaCl/CaSO_4$	— drilling evaporite beds where the systems are allowed to salt/gyp over for rheology control (eg.) DRUMHELLER
S.P.M.	— long Cretaceous sections in the foothills disturbed belt (eg.) JUMPING POUND — where good rheological properties are required for hole cleaning (eg.) PEACE RIVER
FRESH WATER	— all others

EXPERIMENTAL DRILLING FLUIDS
1984

DRILLING FLUID	NUMBER OF TESTS
Foam	2
Mist	1
Air	4
Total	7

These fluids have saved Shell $\approx$ \$500 k. Shell is presently still on a learning curve trying to improve their drilling performance with these fluids. Primary application of these fluids is in the Rocky Mountain Overthrust Belt where SPM is used.

ADVANTAGES OF SPM SYSTEMS

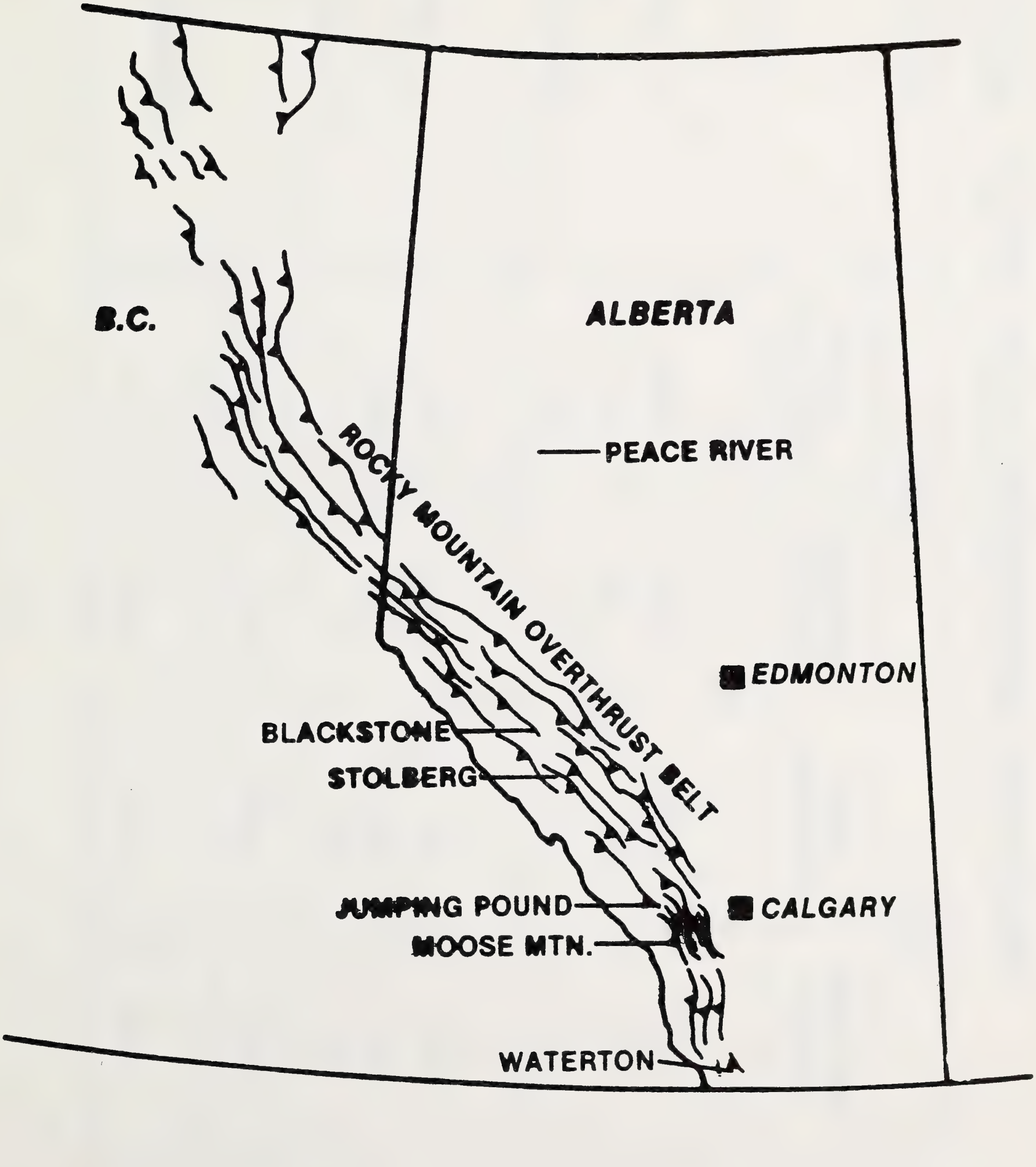
1. Faster R.O.P.

2. Better hole cleaning
   - — less stuck pipe

3. Reduced hole enlargement
   - — less cement and mud used
   - — better cement jobs
   - — better log and D.S.T. quality
   - — less deviation
   - — reduced rig time lost due to reaming and cleaning

4. Smaller sumps

SHELL POLYMER MUD APPLICATIONS



DRILLING FLUID ENGINEERING EFFORT

AREA OF EFFORT	1982		1985	
	TOTAL MANYEAR	DRILLING FLUIDS	TOTAL MANYEAR	DRILLING FLUIDS
SELECTION				
Drilling Engineering	16.0	0.8	15.0	0.8
Drilling Operations	2.0	0.1	3.0	0.2
Calgary Research Centre	0	0	4.0	2.5
DISPOSAL				
Drilling Engineering	1.0	1.0	0	0
Logistics	6.0	0.5	6.0	1.0
Calgary Research Centre	0	0	1.0	1.0
TOTAL	25.0	2.4	29.0	5.5
% OF TOTAL ENGINEERING EFFORT	—	9.6	—	19.0

ENVIRONMENTAL PLANNING, OPERATING PRACTICES AND RECLAMATION PROCEDURES

J.D. Scott[1]

Shell's approach to handling a basic gel, KCl or any other drilling fluid system is to have a plan in place designed to:

- minimize disturbance of the environment
- minimize the use of water
- minimize generation of drilling waste (liquids/solids)
- maximize re-use of drilling fluid
- ensure appropriate measures are taken to contain and properly dispose of drilling wastes
- protect the public, wildlife, vegetation and waters
- return the disturbed lands to as near the original contour and productivity as practical at the earliest date on completion of the land use

The complexity of the plan may be site specific for each drilling location based on:

- well site topography
- location (agricultural, forest, waste lands, etc.)
- soil conditions
- time of activity (winter, spring, summer)
- operating exposure time based on the number of drilling days with respect to drilling depth and formation conditions
- type of drilling fluid used to drill the well to its objective on schedule, safely and economically
- volume of drilling waste generated based on the number of drilling days which varies with drilling depth, hole size, type of drilling fluid used and type of drilling formations

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[1] Manager, Logistics, Drilling Division, Shell Canada Resources Ltd., Calgary, Alberta.

The basic phases of the plan include:

- Base Data (site specific information)
- Containment
- Operating Procedures
- Treatment and Disposal
- Reclamation

Operating criteria for each phase of plan:

Base Data

- surface location of well
- drilling depth, time and season
- type of drilling fluid
- volume of drilling fluids and solids expected
- site inspection
  - determine surface/sub-surface soil condition by boring test holes or excavating test pits
  - establish water table and water quality
  - establish on or off lease sump requirement
  - design construction requirements for well site
- communicate with regulatory agencies and obtain approvals.

Containment

- Sump Construction
  - Gel sump requires about 50% more capacity than a KCl system to higher volume of solids generated.
  - Sump capacity must be adequate for anticipated volume of fluids and solids and include a minimum of one metre free board.

    Ref: VG #1 (basic rule of thumb is 0.78-1.3 m^3 per metre)
  - Sump excavated below grade on high side of lease in impervious undisturbed subsoil above water table.

    Ref: VG #2
- Sump Location
  - On lease preferred immediately adjacent to drilling rig allowing direct discharge of solids or fluids from solids control equipment or mud tanks.

    Ref: VG #3

    - Off-lease option based on insufficient sump volume or unsuitable soil conditions for excavation of a sump on lease. Ideally the remote sump should be located in the closest location with suitable soil to minimize the cost of transporting the drilling wastes. However, consideration must be given to visual impact regarding the public and disturbance to wildlife. Remote sumps may require fencing to prevent wildlife, people and livestock from entering the sump.
    - Sump options may require use of synthetic liners, clay or other sealing agents in areas where soil is not impervious.
    - An off-lease sump requires the placement of surface or buried metal tanks on the drilling lease to hold fluids/solids for transport by trucks to the off lease sump.

      Ref: VG #4

Operating Procedure

- Minimum Generation of Waste Fluids
    - Efficient layout of wellsite to provide proper drainage to avoid surface runoff into sump.

      Ref: VG #5
    - Use of efficient solids control equipment.
    - Use of high pressure low volume wash guns.
- Maximize Re-use of Drilling Fluids
    - Use of efficient sump design to facilitate recycling of fluid and separate contaminated fluids.

      Ref: VG #6 Shallow Hole Recirculating Sump
      #7 Recirculating Sump
      #8 Recirculating Sump (Alternate Layout)
      #9 C Type Recirculating Sump w/Main Sump
    - Use of biodegradable non-toxic, non-foaming rig wash.
    - Re-use of drilling fluid at another drill site provided transportation costs are economical.

- Monitor
    - sump volume by placement of markers
    - take daily volume readings
    - maintain efficiency of equipment
    - train personnel and keep them aware of good waste management practices
    - placement and monitoring piezometers
    - electro conductivity surveys.

Treatment and Disposal

- Timing

  1) Production Well - at completion of drilling well to:
      - minimize risk of sump contamination by service rig.
      - allow Production to complete well, tie in facilities and start producing well at earliest date.

  NOTE: Surface farming drilling fluid/sludge/solids will be required off lease as there is not sufficient room on lease due to wellhead production test and producing facilities.

  Ref: VG #9A

  2) Abandoned Well - at earliest date to:
      - avoid sump volume gain from rain/snow.
      - reduce risk of sump contamination by mystery dump of fluids into sump by unknown party.
      - early reclamation of land for re-use.
      - lease may be condusive to land farming depending on final restoration contour. An off-lease disposal area may be required.

- Methods

  1) On Lease Disposal without sampling or treatment is allowed if the fluid volume is less than 6 000 bbls.

  2) Sub-surface Disposal - Ideal for KCl fluids if a disposal well is available within an economical transportation distance from the sump. Fluids may require flocculating to reduce the size of suspended

solids based on the formation characteristics of the disposal well.

3) Off-Lease Disposal - Considered when volumes in excess of 6 000 bbls are generated and downhole disposal is not feasible. This disposal option requires proper sampling and treatment of the fluid to meet the requirement of ERCB.

NOTE: KCl drilling fluids will likely exceed the guideline values therefore the fluid is treated to remove suspended solids and organics and disposed of off lease in an approved area at a restricted chloride application of 400 lbs. per acre.

- Solids and sludges are mixed with excavated soil dried or stiffened and buried in the base of the sump then capped with a compacted layer of clay (minimum of one metre) and crowned to ensure good surface drainage. In the case of large volumes additional trenches or pits are excavated on lease to achieve total disposal.

Ref: VG #10

Reclamation

- On completion of the sump squeeze a period of time is allowed to rectify any settlement.
- The wellsite is recontoured to its original state, layers of salvaged topsoil placed over the surface.
- Fertilizer and approved seed mix or planting of trees over the entire surface is accomplished.
- All work is done in co-operation with the regulatory agencies and a reclamation certificate is received when restoration considered satisfactory.

NOTE: A producing wellsite is only partially restored during the producing life of the well. This means the working surface and access would not bee seeded until total abandonment of the wellsite is declared.

RESULTS OF OPERATING PRACTICES

I am not aware of any major problems to date. This can be attributed to:

- corporate level management support in the waste fluid management program.
- effective application of waste management plan.
  Eff: VG #11
- close liaison and co-operation between Shell and regulatory representatives.
- effective preplanning.
- Utilizing competent contractors and state of the are equipment and techniques.
- "NOT BIDDING" waste fluid/solids treatment/disposal and reclamation work. In our opinion the high level of success has been achieved by contracting the work on an hourly basis carrying it out under the close supervision of Shell's Operations Foremen.

RESEARCH

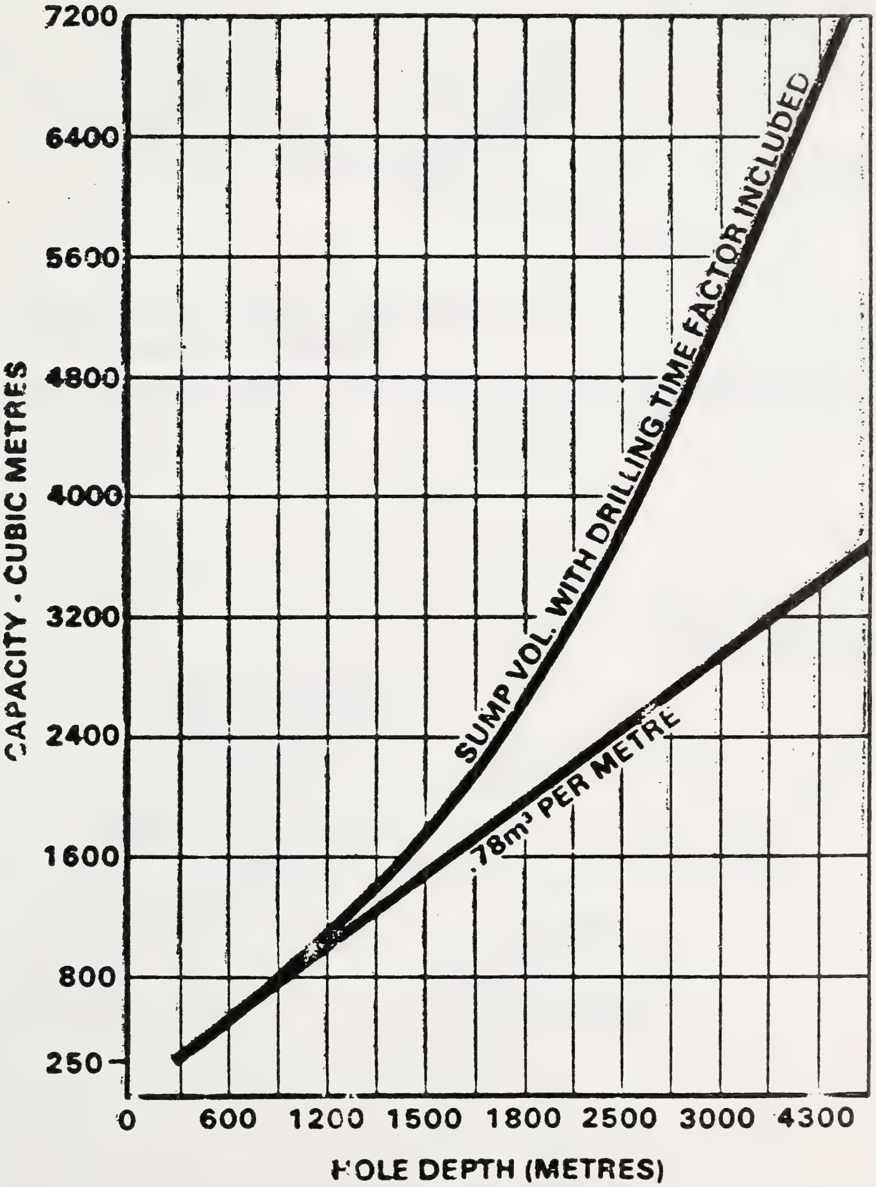
- Two land farming of drilling sludge/solids is being conducted at:
  1) Shell Jumping Pound - KCl Sump
  2) Shell Stolberg - Invert Mud Sump

CONCLUSION

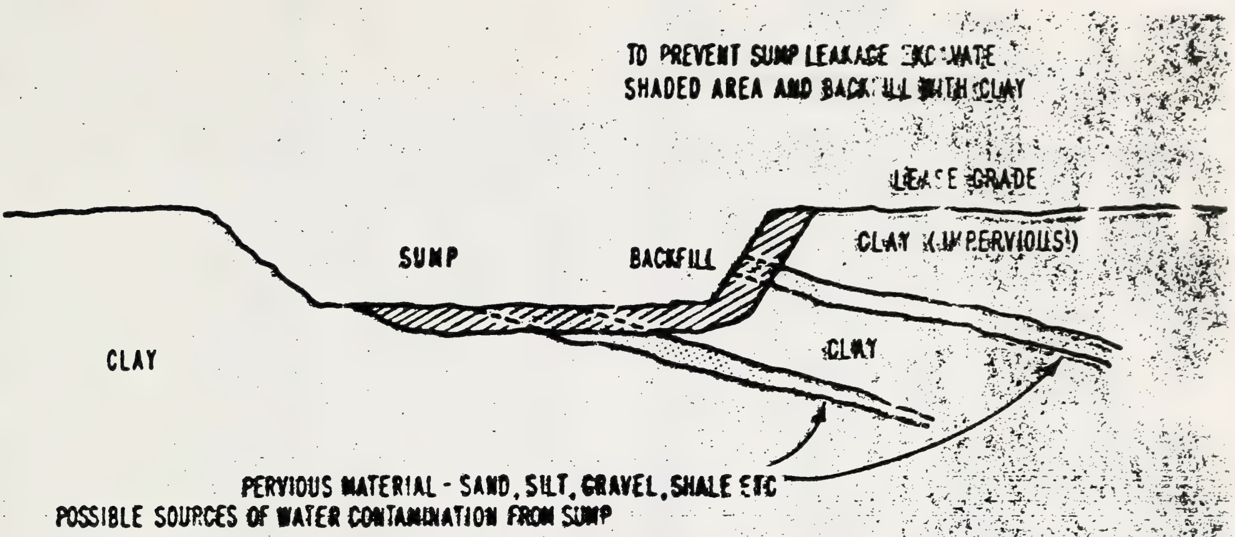
- I concur with Mr. N. Barnes' observation that the best field results are achieved by using the same person(s) that constructed the wellsite to treat/dispose of waste fluids and do the final reclamation.
- Caution with respect to change in regulations:
  - suggested changes by joint industry/government co-ordinated
  - change may only be required in site specific areas
  - ensure change does not create more problems than it resolves

- Washing or dilution of drilling fluids/sludges/solids will increase the volume of fresh waster used and significantly increase operating costs.
- Land farming drilling fluids/sludges/solids will require a significant additional disturbance of land.
- Significant increase in costs could affect the viability of a project.
- A balanced co-operative effort between industry and government, applying practical procedures can achieve a common goal of conducting work with minimal disturbance to the environment, public and wildlife at minimum cost.

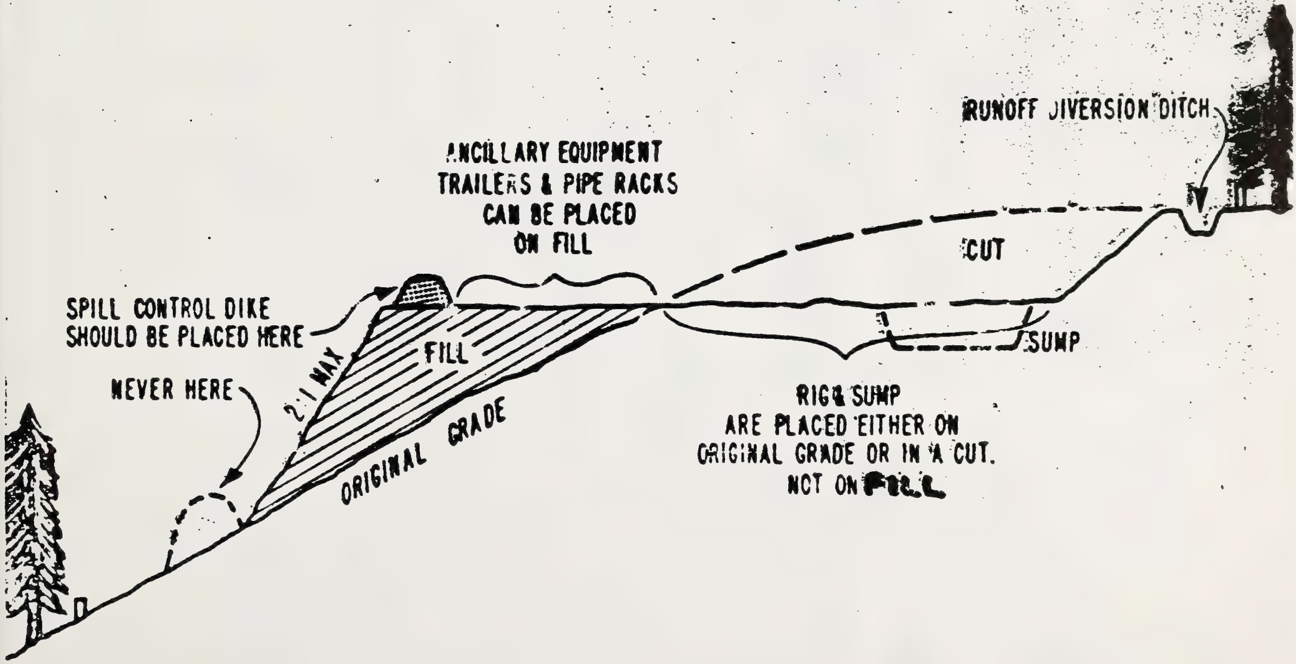
SUMP CAPACITY VS HOLE DEPTH



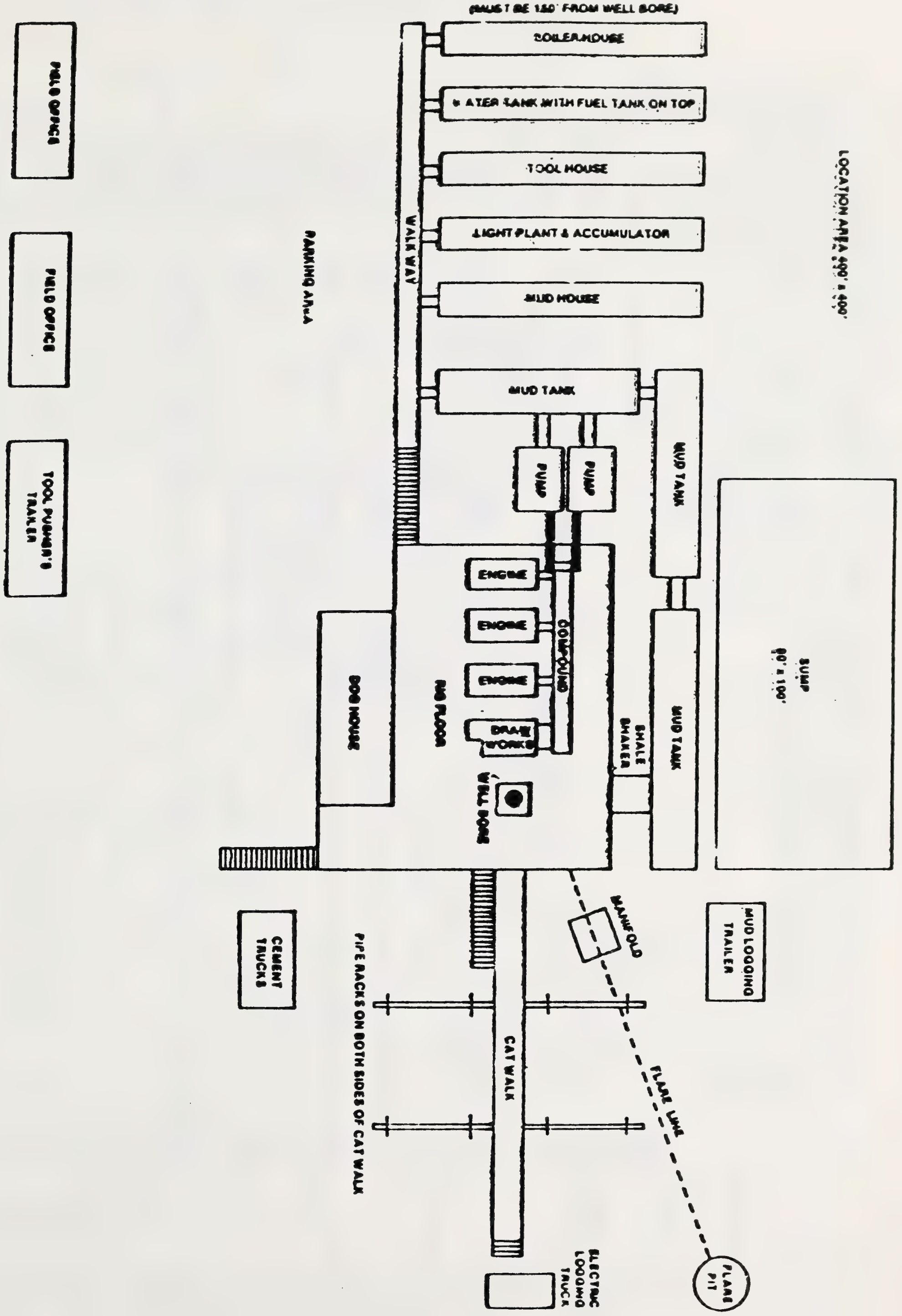
NOTE: ADD 1.3 METRES TO SUMP DEPTH FOR ADEQUATE FREEBOARD


TO PREVENT SUMP LEAKAGE EXCAVATE
SHADED AREA AND BACKFILL WITH CLAY
LEASE GRADE
SUMP
BACKFILL
CLAY (IMPERVIOUS!)
CLAY
CLAY
PERVIOUS MATERIAL - SAND, SILT, GRAVEL, SHALE ETC
POSSIBLE SOURCES OF WATER CONTAMINATION FROM SUMP

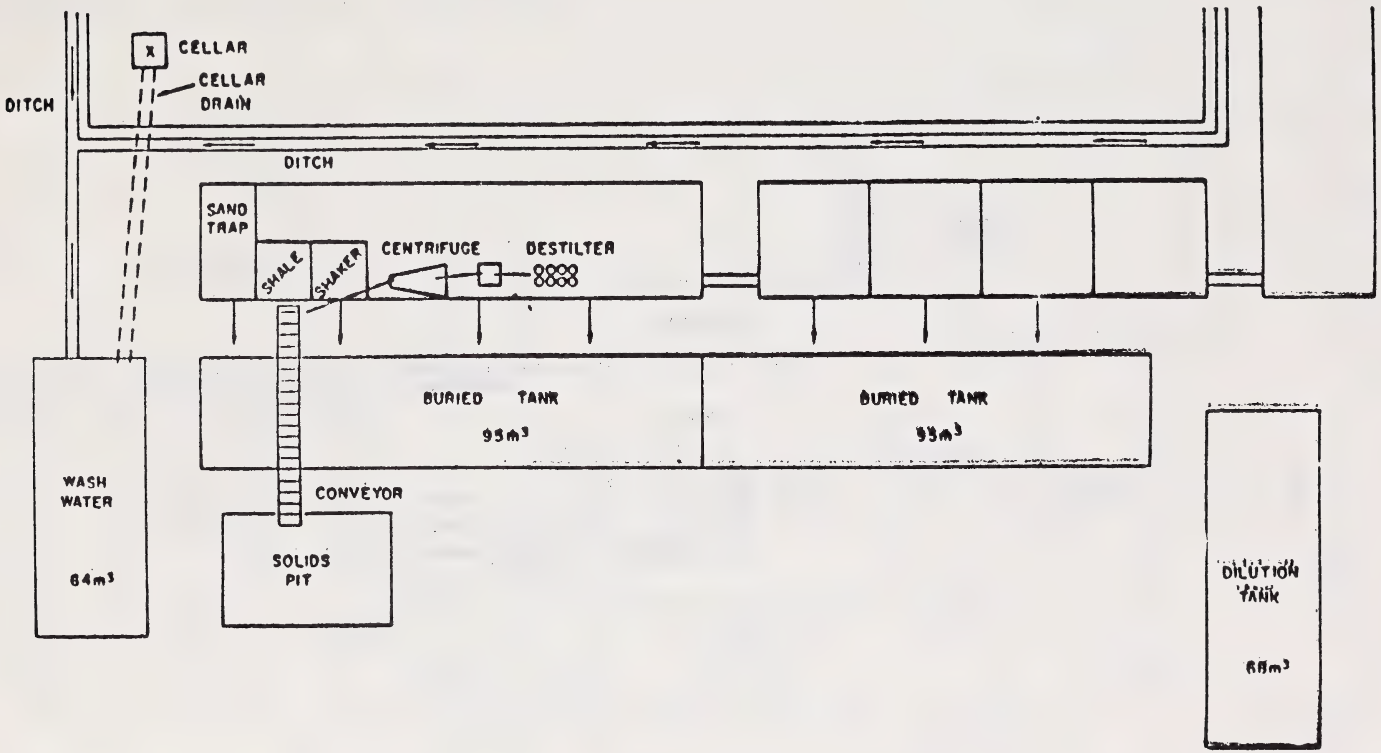
A. POTENTIAL FOR GROUNDWATER CONTAMINATION



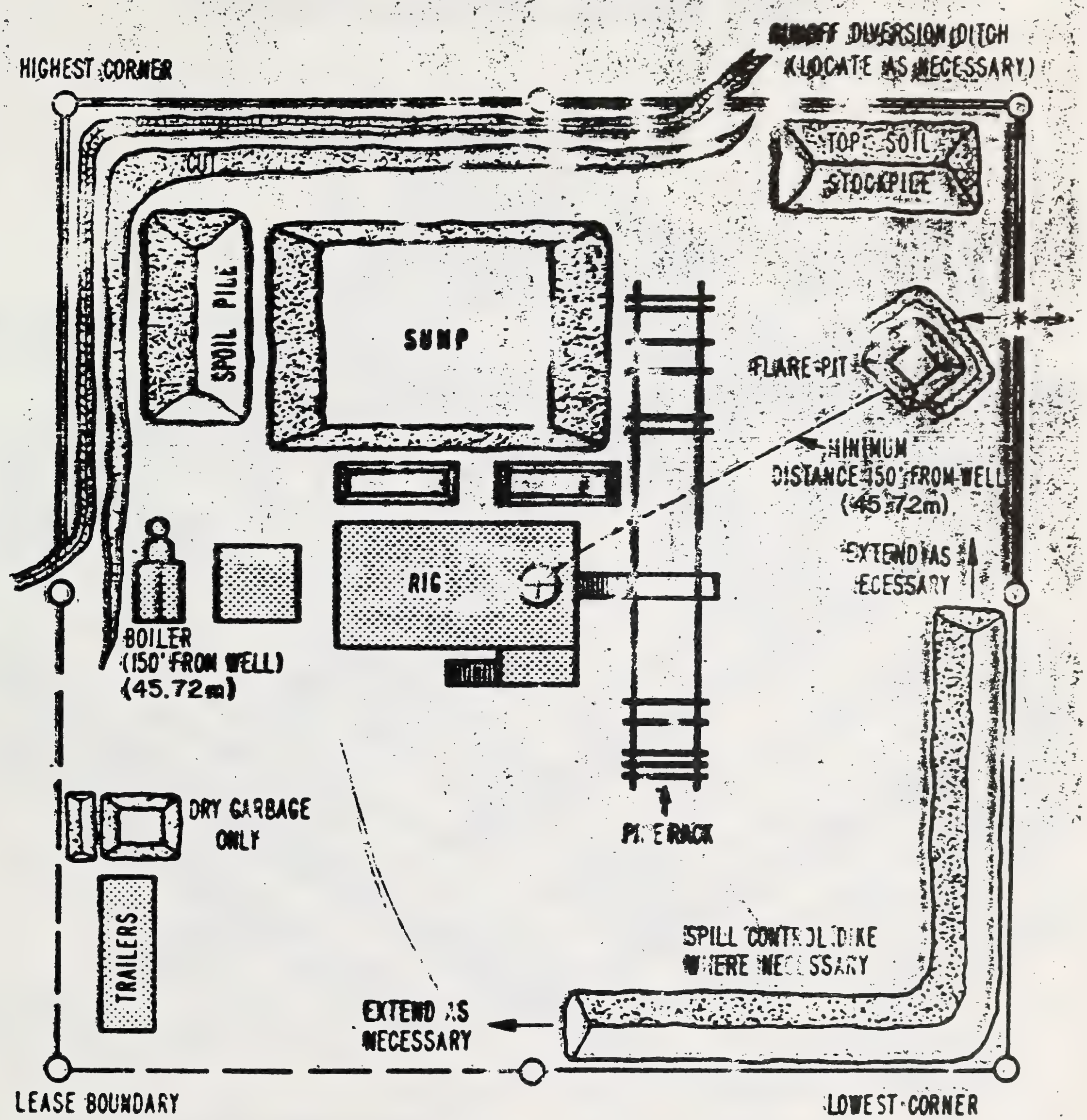
B. CROSS SECTION OF LEASE ON SLOPING GROUND


(MUST BE 150' FROM WELL BORE)
BOILER HOUSE
WATER TANK WITH FUEL TANK ON TOP
TOOL HOUSE
LIGHT PLANT & ACCUMULATOR
MUD HOUSE
LOCATION AREA 400' x 400'
FIELD OFFICE
FIELD OFFICE
TOOL PUSHER'S TRAILER
PARKING AREA
WALK WAY
MUD TANK
PUMP
PUMP
MUD TANK
SUMP
80' x 100'
ENGINE
ENGINE
ENGINE
COMPOUND
DRAW WORKS
RIG FLOOR
DOG HOUSE
WELL BORE
SHALE SHAKER
MUD TANK
MANIFOLD
MUD LOGGING TRAILER
CEMENT TRUCKS
PIPE RACKS ON BOTH SIDES OF CAT WALK
CAT WALK
FLARE LINE
FLARE PIT
ELECTRIC LOGGING TRUCK

LEASE LAY-OUT FOR OFF-LEASE DISPOSAL



TYPICAL LEASE LAYOUT

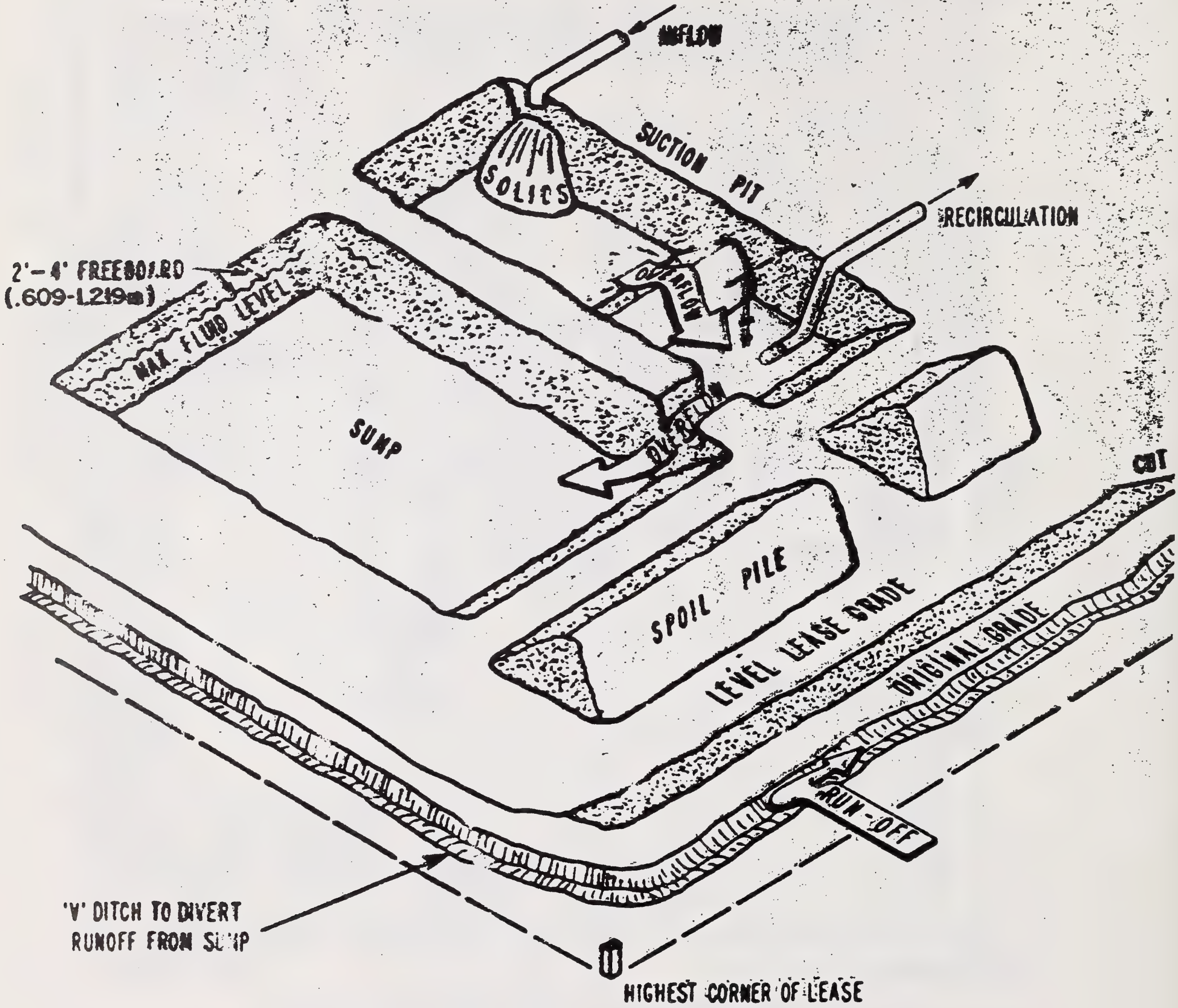


* INSURE ADEQUATE CLEARANCE BETWEEN FLARE PIT & TREES IN FORESTED AREAS.

LEGEND

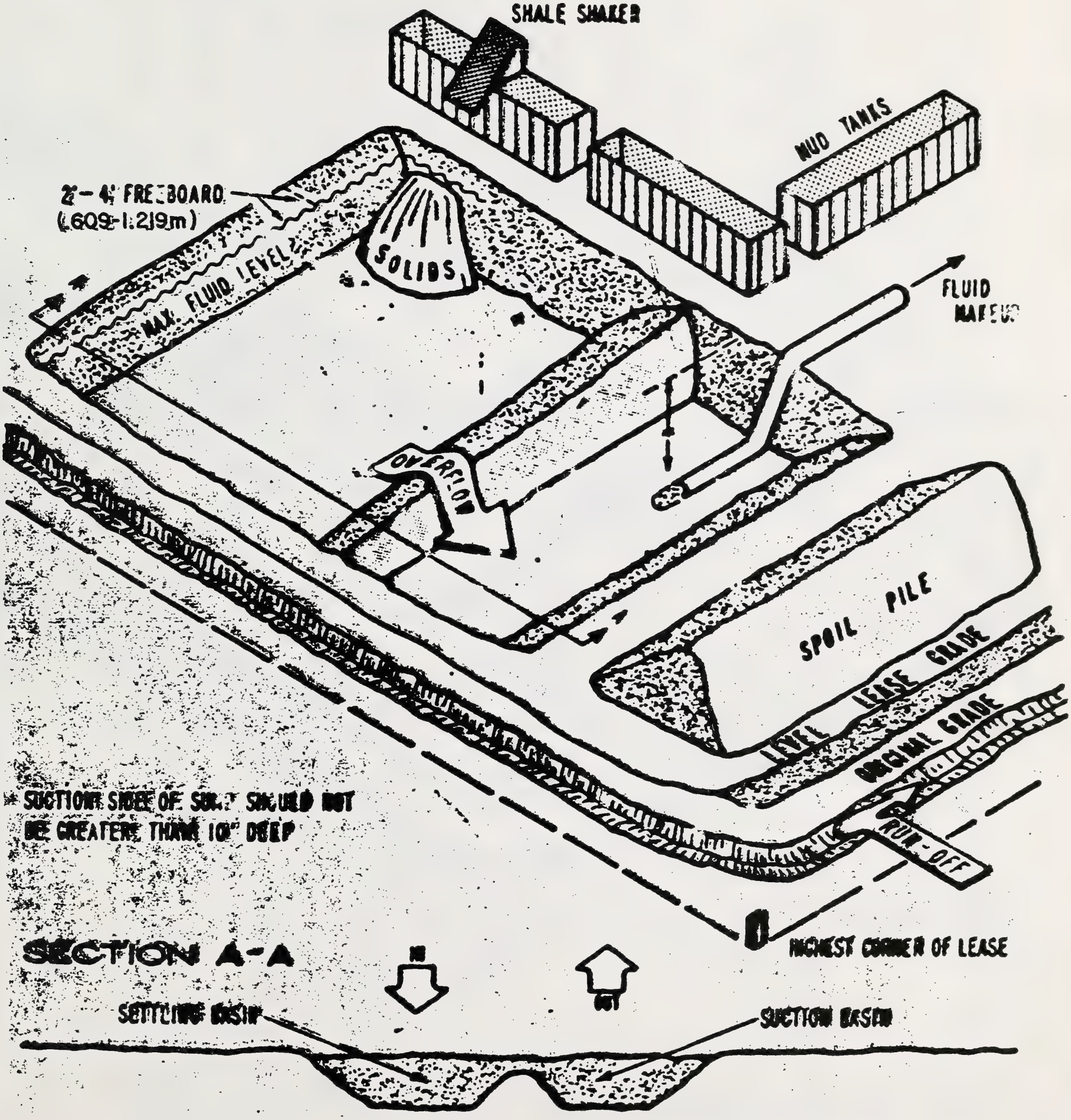
○━━━○	NO ACCESS ROAD ENTRANCE ALONG THIS SIDE OF LEASE
○───○	OPTIONAL ACCESS ROAD ENTRANCE ALONG THIS SIDE
○– – –○	PREFERABLE ACCESS ROAD ENTRANCE ALONG THIS SIDE

SHALLOW HOLE RECIRCULATING SUMP

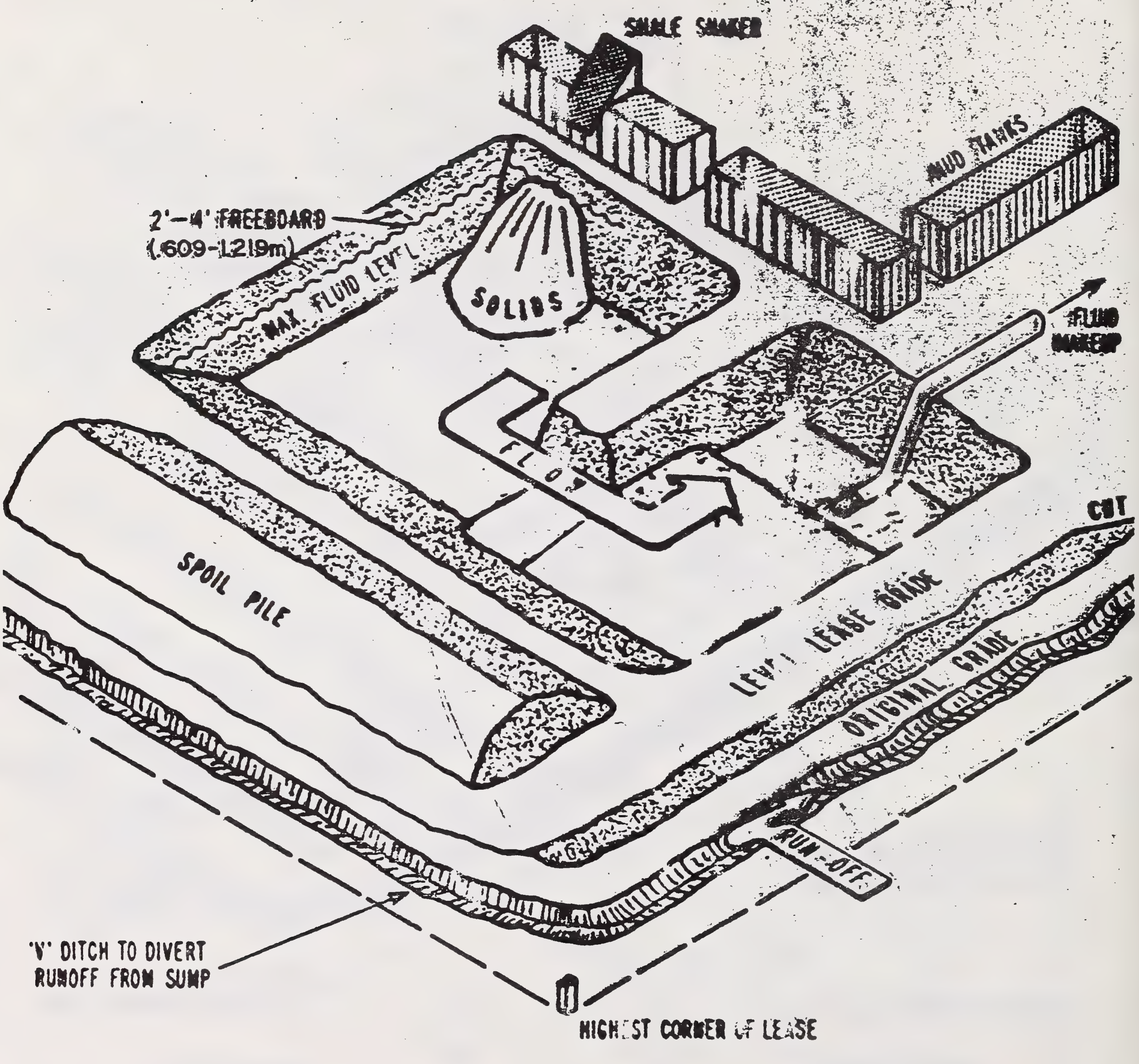


* SUCTION SIDE OF PIT SHOULD NOT BE GREATER THAN 10FT. DEEP.

RECIRCULATING SUMP

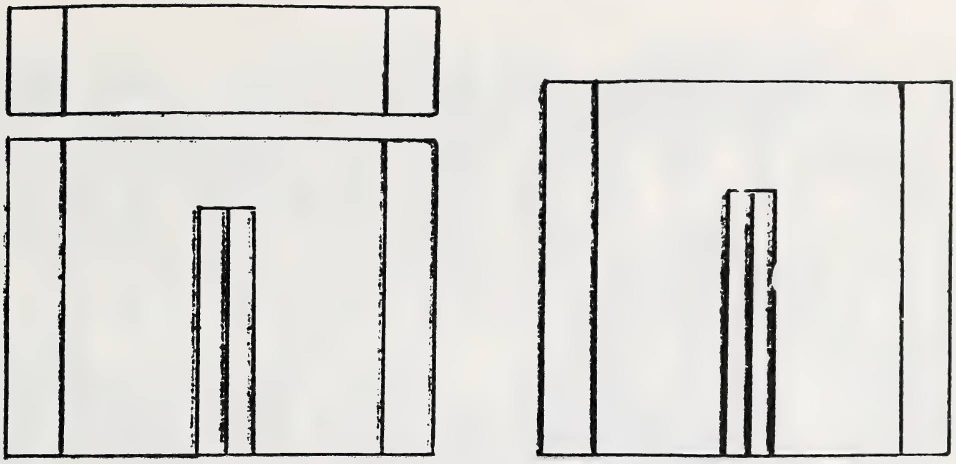


RECIRCULATING SUMP
ALTERNATIVE LAYOUT



* SUCTION BASIN SHOULD NOT BE DEEPER THAN 10FT.

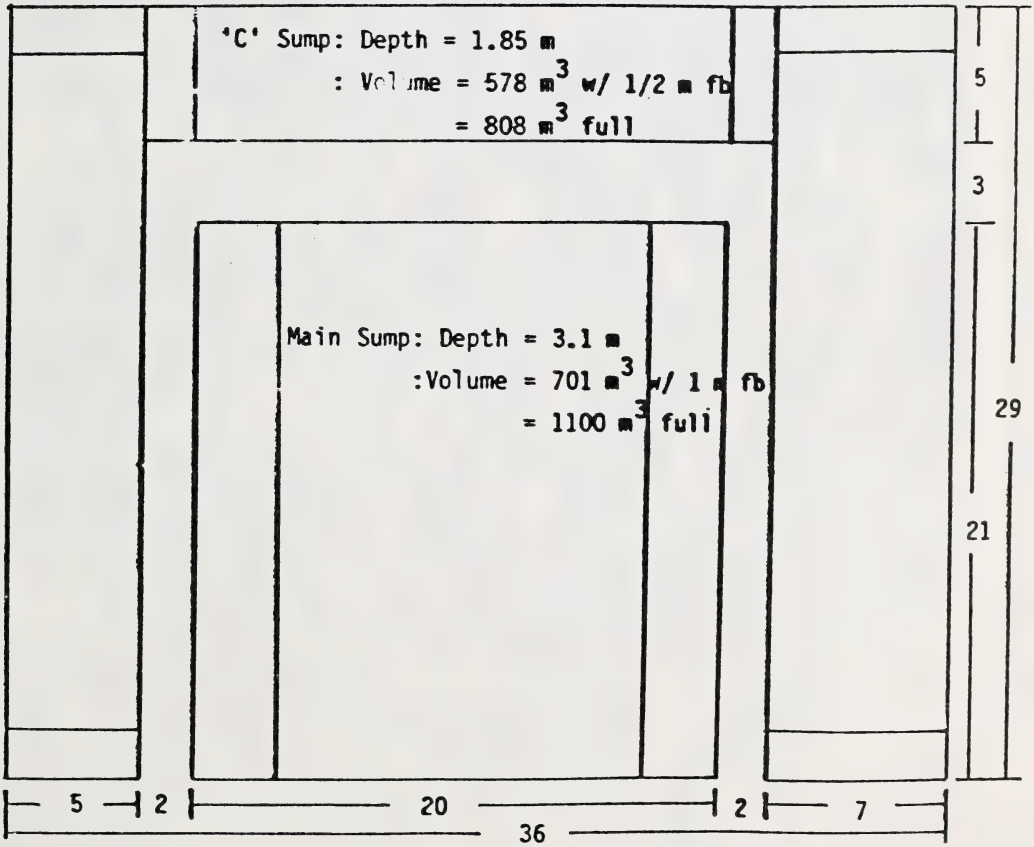
SUMP DESIGN : PLAINS WELLS



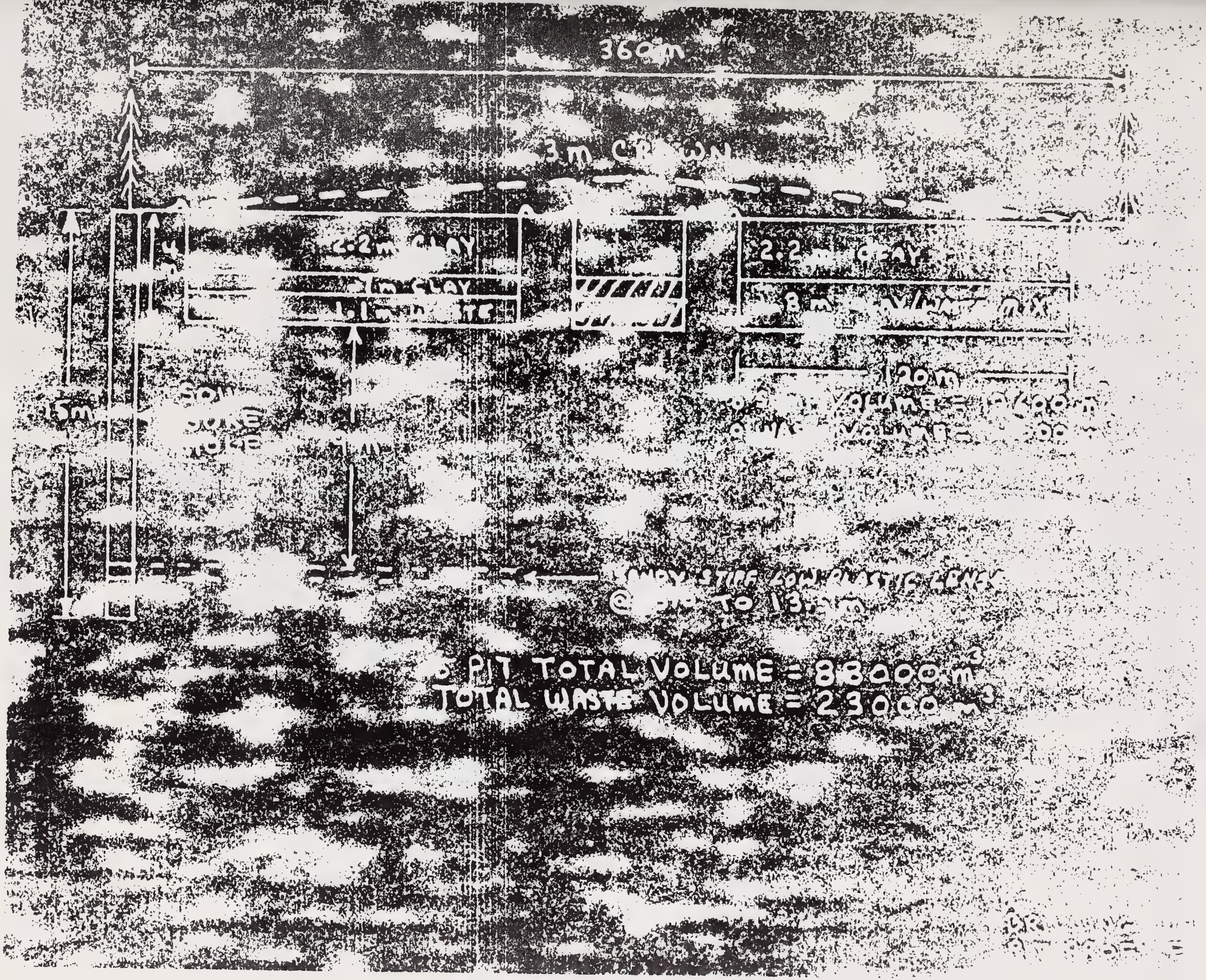
Conventional Recirculating Sump

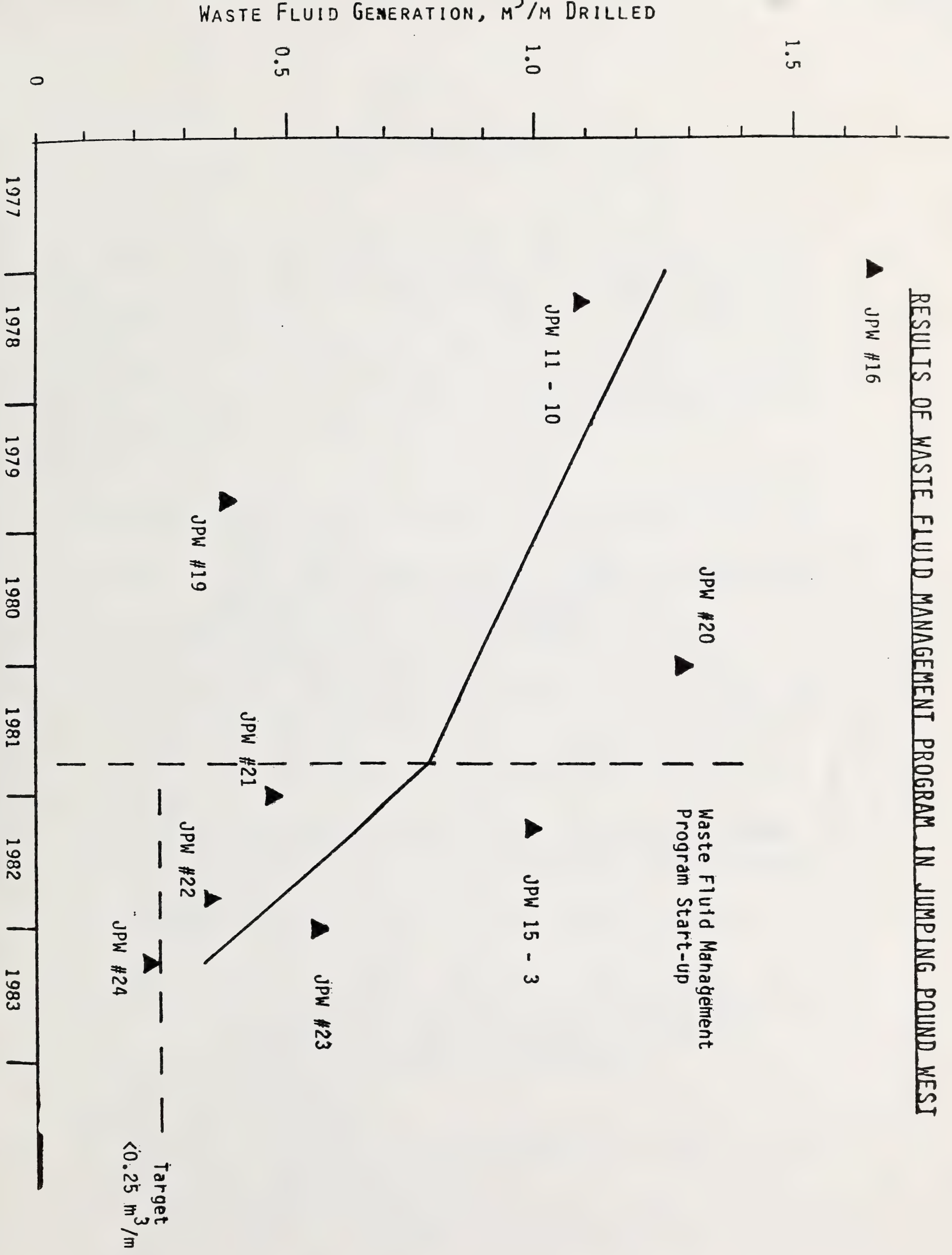
w/Reserve Pit

w/o Reserve Pit



C - type Recirculating Sump w/ Main Sump


360m
3m CROWN
2.2m CLAY
1m CLAY
1.1m
2.2m CLAY
8m
MIX
120m
VOLUME =
VOLUME =
15m
50m
4
SANDY STIFF LOW PLASTIC CLAY
@ TO 13.
PIT TOTAL VOLUME = 88000 m3
TOTAL WASTE VOLUME = 23000 m3



RESULTS OF WASTE FLUID MANAGEMENT PROGRAM IN JUMPING POUND WEST

APPENDIX A

FOLLOW-UP QUESTIONNAIRE

Because the two-day session on gel and saline-based drilling wastes was really a conference format and not a workshop format, this preventing much discussion or audience feedback, a questionnaire was sent out to all who registered for the session. Thirty-five replies were received for the seven questions asked. The information from each reply is summarized as completely and concisely as possible and is presented below.

A) QUESTION 1: **Did you find the workshop beneficial? If so, why, and if not, why?**

Reply: Every reply affirmed that the session was beneficial. The main benefits identified were:

- government-industry exchange that was overdue
- covered relevant topic areas
- helped identify all the players concerned with the problem of drilling waste disposal
- provided idea of scope and range of topics and identified areas of concern
- provided a good forum for people interaction and idean exchanges
- showed that salt mud use required more thought before industry programmed use (an industry comment)
- showed that more work needs to be done in many areas

B) QUESTION 2: **Was it too long, too short or too technical? What would you change about the length and/or quality?**

- 21 people replied that the length was satisfactory
- two stated "too long"
- two stated "too short"
- eight stated the sessions were too technical, at least in some areas, such as the mud chemistry
- two stated the sessions could have been more technical
- most stated that the technicality was good

Several people criticized the lack of discussion and the poor control exercised by chairmen. More case studies and examination of waste disposal methodologies and pollution solution techniques were also requested. The response to Question #2 illustrated the difficulty that is always confronted when dealing with environmental understanding and pollution control. There are many resource disciplines that must be understood. There are also different levels of technical understanding possessed by the many people involved in the waste disposal decision-making arena. How to tailor research needs, information and end user environmental control procedures to the various audiences remains a problem.

C) QUESTION 3: **Whas the format acceptable? Would you like more quetion time, time for group discussion, panel confrontation?**

- 27 people indicated that more time was needed for question and answer sessions, panel discussion and group discussion
- eight people indicated that the format was acceptable
- more interchange among experts was needed. This might have been accomplished by a panel discussion. The large attendance precluded group discussions.

D) QUESTION 4: **Would another workshop on the same topic be desired? If so, is there a topic or subject area that should be focused on?**

- ongoing information sessions like this one are very informative and should be continued after experimental data becomes available
- technical areas need further study such as: saline muds and their effect on soils and plants; sump design and construction; deep disposal wells for salt solutions and associated concerns; salt movement in soil and groundwater
- a session could be held where industry and government changed roles and proposals then put forward
- a session should be aimed at field foremen and should stress field operational concerns and procedures for different waste disposal scenarios

- discuss results of different disposal methods
- look at examples of where reclamation certificates were issued and what agreements were reached that led to the certificate

E) QUESTION 5: **What method of drilling waste disposal do you prefer? Do you have any environmental disposal experience to support your viewpoint? If so, please explain these experiences.**

- several said land spreading and burial have pros and cons. Research is needed for both areas. Disposal depends on constituents of waste and treatment methods prior to disposal.
- dispose of waste at a government approved and controlled facility
- the whole waste pit needs to be treated
- minimize waste and have no sumps
- land spreading - good amendment for acid and sandy soils
- KCl and NaCl wastes should be washed of salts and remaining solids buried. The supernatant salt water should be pumped downhole
- burial preferred (industry viewpoint) - since 1969, more than 100 wells drilled with KCl and wastes were buried - to date no detrimental effects are showing. Most salt problems seem to be caused by surface spills.
- 10 replies favored land spreading
- burial (one government viewpoint) seems to work reasonably well in southeastern Alberta
- subsurface disposal of salt solutions by deep well injection

F) QUESTION 6: **Would you like to see a comparison of a land application trial, a full treatment by a system such as NEYRFOR or Hi-Tech and a burial system?**

- 26 people answered yes to the above question
- five answered no. (These were industry and treatment companies.)
- need more information about the various disposal techniques and how they apply to different mud types
- must consider costs, management factors, trade-off decisions regarding costs and vegetation, soils and groundwater damage (if any)

- must compare effects of burial versus land application on soils, vegetation and groundwater
- must be careful about extrapolating findings from any test because of surface and subsurface variability from one site to another
- sodic wastes should probably not be landspread
- should be encouraging other work instead of treatment or waste detoxification. Work such as:
    - mud formulation - use non-toxic systems
    - recycling technology
    - treatment prior to disposal
    - guidelines should take into consideration the characteristics of receiving soils
- encourage systems such as NEYRFOR and Hi-Tech

G) QUESTION 7: **What specific areas do you feel need to be studied either by field trial or by lab testing, etc.? For example:**

- **land farming**
- **toxic concerns with burial**
- **groundwater contamination**

The major request for future study was to determine the specific toxic concerns for land application and burial. Questions posed were:

- what toxins are produced when muds are buried and what are the effects on groundwater, soils and vegetation?
- what toxins are produced when muds are land applied and what are the effects on soils, vegetation and groundwater?
- migration potential of salts and other toxins
- for land application
    - salt loads permissible
    - method, kind and amounts of chemical amendment
    - area required
    - method of applying waste to land
    - ease or speed of organic degradation
    - cost effectiveness and time scale needed

  - when have high volumes of solids - logistics of waste movement and area required
- more work needed to develop environmentally acceptable muds, recycling technology and detoxification before disposal
- subsurface deep well disposal and when allowable requires investigation
- optimum method of salt extraction from wastes

N.L.C. - B.N.C.
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